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This report describes research conducted to develop an analytical characterization of Navy command and control decisions. The objective of this research is to establish a framework for assessing the nature of tactical decisions and the characteristics of proposed decision aids on comparable scales in order to see whether the aids are suited to the needs of Navy decision-makers.

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20. ABSTRACT (cont)

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March, 1979

Final Report

AN ANALYTIC CHARACTERIZATION OF NAVY COMMAND AND CONTROL DECISIONS

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SUMMARY

This report describes research conducted by Applied Decision Analysis for the Office of Naval Research to develop an analytical characterization of Navy command and control decisions. The objective of this research is to establish a procedure for assessing the nature of tactical decisions and the characteristics of proposed decision aids on comparable scales in order to see whether the aids are suited to the needs of Navy decision-makers. The result of this research is a logical framework for evaluating the suitability of existing and proposed decision aids, and for guiding their development.

This framework is based on three closely-related taxonomies. The first groups Navy command and control decisions into various categories, defined by the decision-making function in organizations found in the Navy. In this taxonomy, decisions are categorized along several dimensions, including: the level of command at which a decision is made, the type of warfare involved; the function accomplished by the decision (e.g., select assets to accomplish an objective); and the context in which the decision is made (e.g., a planning decision).

The second taxonomy contains a set of analytic measures that can be used to characterize command and control decisions. The characteristics contained in this taxonomy are based on analytic concepts from management science, decision analysis, and related fields, and are relevant to any set of decisions. The taxonomy contains 16 characteristics dealing with the stakes involved in the decision (i.e., the resources at risk), the decision complexity, the information available, and the timing of the decision. Each characteristic is defined as precisely as possible by a technical measure. However, many of the technical measures are based on complex analytical concepts, and thus are difficult to assess. To circumvent this problem, a relatively simple assessment measure is included for each decision

characteristic. Assessments of the characteristics of a variety of tactical command and control decisions were conducted using these measures.

The third taxonomy contains a preliminary set of characteristics that can be used to describe decision-aiding systems. These characteristics include such features as an aid's data processing and storage capability, the complexity of the aid-user interface, and the cost of using the aid. Although further research is needed to define these characteristics rigorously, it is possible to link them to the decision characteristics contained in the second taxonomy. This linkage makes it possible to determine the aid characteristics that are most appropriate for a particular command and control decision, and to evaluate the suitability of existing or proposed decision aids.

I INTRODUCTION

This report describes research conducted by Applied Decision Analysis (ADA) for the Office of Naval Research (ONR) to develop an analytical characterization of Navy command and control decisions. This introduction describes the research objectives, method of approach used to categorize and characterize tactical command and control decisions, and the manner in which the resulting taxonomies can be used to identify and evaluate automated systems and procedures for aiding the decision-making process. Section II describes a method of aggregating the many tactical decisions encountered in Navy command and control into a few basic categories, and explains the rationale for this categorization. Section III discusses a set of analytical characteristics that can be used to assess the nature of each decision category and guide the development of decision aids. Section IV describes the manner in which the decision characteristics can be assessed for each decision category (or for any specific decision), and lists the characteristics of several representative decision categories. Section V contains a preliminary discussion of the characteristics of decision aids, and shows how they can be linked to the taxonomy of decision characteristics. Section VI presents some general conclusions derived from this research.

Purpose of the Research

The ultimate goal of this research is to identify procedures and equipment to assist and improve tactical decision-making at various levels of command in the Navy. As an initial step toward this goal, this research project was established to characterize command and control decisions in analytic terms in order to guide and evaluate the design of decision-aiding systems. In other words, the objective of this research is to establish

a procedure for assessing the nature of naval decisions and the characteristics of proposed decision aids on comparable scales in order to see whether the aids are suited to the needs of Navy decision-makers.

This research is not concerned with the design of a particular decision aid or command and control system. No attempts have been made to evaluate any particular aid. Instead, the research produces a framework for guiding the development of decision-aiding systems and matching the characteristics of proposed systems with characteristics of the decisions they are designed to support.

Method of Approach

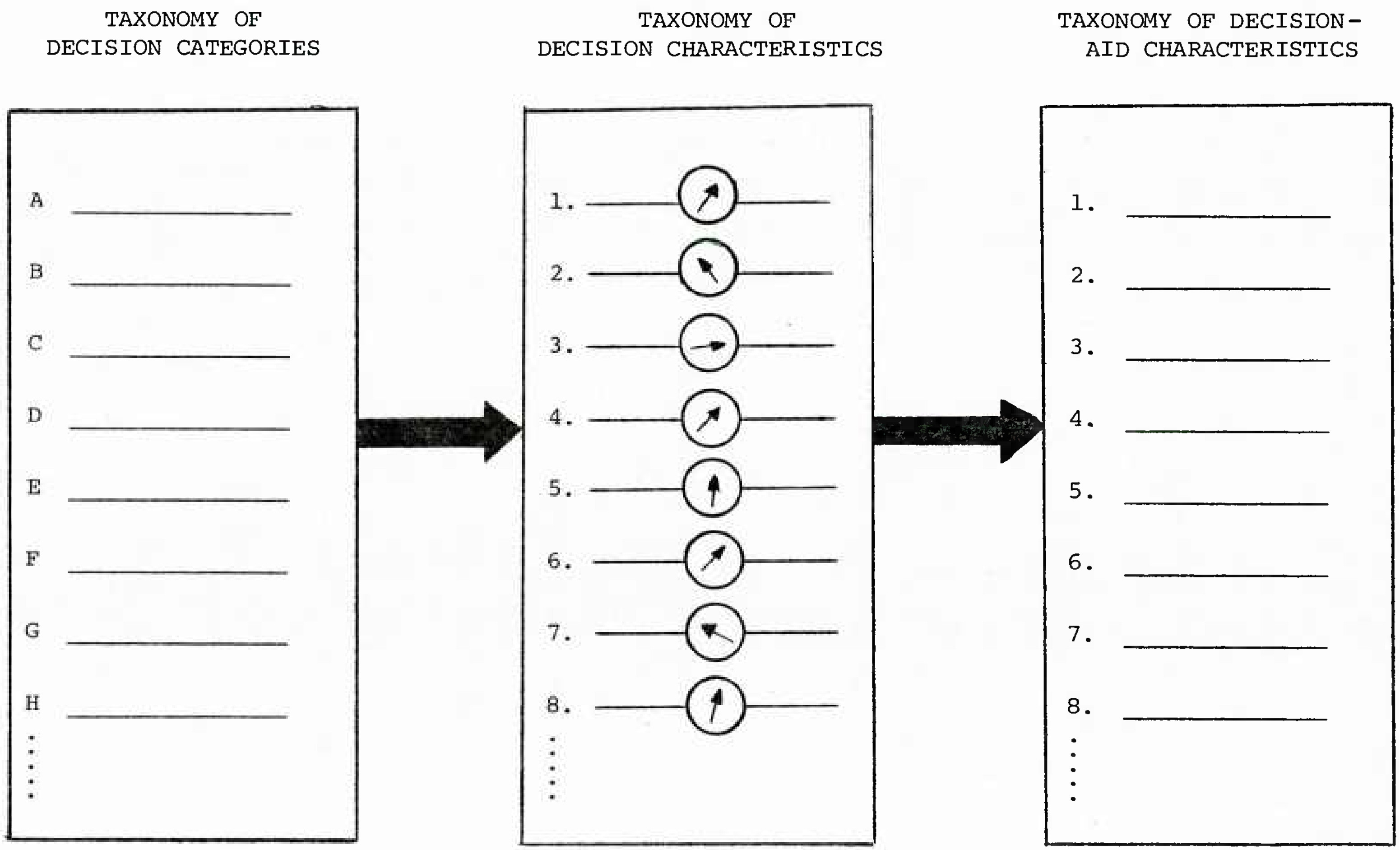
This research was subdivided into three tasks:

1. Identify major decision categories in Navy command and control.
2. Develop an analytic taxonomy of decision characteristics.
3. Apply the taxonomy of decision characteristics to representative categories of command and control decisions, and develop preliminary guidelines for using this information to evaluate decision aids.

These research tasks have resulted in three closely-related taxonomies. The first, described in Section II, is based on the work of Task 1. It groups Navy command and control decisions into various categories. The second taxonomy, described in Section III, is based on the work of Task 2. It contains a set of attributes or analytic measures that can be used to characterize each of the decision categories. The third taxonomy contains a similar set of attributes that can be used to characterize decision-aiding systems. A preliminary version of the third taxonomy is discussed in Section V. However, further development of this taxonomy is beyond the scope of the research described here, and additional research will be needed to make this taxonomy operational. The relationships among the taxonomies are depicted in schematic form in Figure 1.

FIGURE 1

THE RELATIONSHIPS AMONG THE TAXONOMIES FOR CHARACTERIZING TACTICAL DECISIONS



The first taxonomy attempts to break down the entire spectrum of naval tactical decisions into a relatively small number of categories. Decisions are categorized along four dimensions: level of command, type of warfare, decision function, and decision context. A set of descriptors is given for each dimension. For example, with respect to level of command, the available descriptors are fleet, task force and unit. A specific decision is categorized by selecting the appropriate description for each of the four dimensions. The dimensions and the available descriptors are presented in Section II. An extensive set of examples is also given in that section.

The first taxonomy defines a set of decision categories, as shown on the left side of Figure 1. Each of the decision categories (or any specific decision) can be mapped into the second taxonomy, that of decision characteristics. The mapping results in each decision category being described by a series of analytic measures, one for each characteristic in the second taxonomy. In Figure 1, each of these measures is represented by a small meter to indicate that the same list of characteristics will be used to measure all of the decision categories. The second taxonomy consists of sixteen characteristics. Among them are such things as the decision-maker's resources, the number of decision strategies available to the decision-maker, the quantity of information related to the decision-maker, and the time available for decision-making.

Each of the decision characteristics in the second taxonomy has implications for the design of decision-aiding procedures and equipment. For instance, characteristics such as the number of decision strategies and the number of significant factors in the decision clearly affect the storage and processing requirements of an aid. A decision characterized by a large volume of information calls for an aid with an extensive communications capability. A decision that must be made in a short period of time requires an aid that can respond quickly. Thus, the decision characteristics can be mapped into a third taxonomy describing the characteristics of decision

aids. This relationship is also shown in Figure 1. The result is a set of desired decision-aid characteristics. Some examples of characteristics in the third taxonomy are: the unit cost of the aid (including an appropriate share of research and development costs), the extent to which the aid can monitor current events and update data, the aid's communications capability, and the complexity of the interface between the aid and the user.

The framework in Figure 1 provides a linkage between decision categories, decision characteristics, and aid characteristics. This linkage allows us to translate the characteristics of a particular decision category, as measured by the second taxonomy, into a desired set of characteristics for an aid for the category. For instance, a decision characterized by a large number of possible decision strategies and outcome variables, a well-defined structure, and the need for approval at higher levels of command will require an aid that is capable of efficiently optimizing a pre-programmed model with many decision variables; evaluating the outcomes associated with each decision strategy along several dimensions and combining them to produce a single, composite objective function; and storing a summary of the decision logic in a form that can be presented to higher levels of command.

As Figure 1 demonstrates, the taxonomies start with a decision category and determine the desirable characteristics of a corresponding decision aid. Thus, if we start with a proposed decision aid and try to evaluate its usefulness, it is first necessary to identify the decisions or decision categories to which it can be applied in order to use the taxonomies. Once this is done, the taxonomies will indicate the characteristics that the aid should have, and these can be compared with the aid's actual characteristics to test its appropriateness.

If it is not clear which decision categories can be supported by a proposed decision aid, categories can be identified by attempting to match the decision-aid characteristics associated with each category with

those of the proposed aid. However, this process is time consuming and probably unnecessary. Most decision-aiding systems are proposed with a particular set of decisions in mind.

The mapping between the first two taxonomies shown in Figure 1 (decision categories and decision characteristics) is the subject of Task 3 and is discussed in Section IV. The mapping between the second and third taxonomies (the characteristics of decisions and decision aids) is discussed in Section V of this report. However, the taxonomy of decision-aid characteristics and the linkages between it and the taxonomy of decision characteristics is preliminary. Further research will be required to make them operational.

The taxonomies described in this report are based on information from a variety of sources, including: previous research on the nature of tactical command and control systems in the Navy, discussions with individuals in other organizations doing similar research, interviews with Navy personnel and visits to command and control facilities, and a review of the Navy manuals and publications dealing with tactical decision-making.

Only a few previous research projects have attempted to characterize tactical command and control decisions in analytic terms. Some of this research was done for the Operational Decision Aids Program of the Office of Naval Research; this work focuses on tactical command and control decisions made by a task force commander and his staff.[1] Other studies have produced general-purpose taxonomies that can be applied to almost any area of management-level decision-making.[2]

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1. See "The Naval Task Force Decision Environment," by Payne, Miller, and Rowney, SRI Technical Report NWRC-TR-8, 1974.

2. See "Selecting Analytical Approaches for Decision Situations," Volumes 1, 2, and 3, by Brown and Ulvila, Decisions and Designs, Inc. Technical Report TR 77-7-25, 1977, and "The Development of Automated Aids for Decision Analysis," by Miller, Merkhofer, Howard, Matheson, and Rice, SRI Technical Report 3309, 1976.

Several other research organizations are investigating similar topics, including Navy organizations such as the Naval Ocean Systems Center, and private contractors. A project that is closely related to the work described here is research being done by Perceptronics to develop an analytic taxonomy of tactical command and control decisions in the Marine Corps. The taxonomies described here reflect the many helpful comments and suggestions made by researchers from these organizations.

The taxonomies have also been discussed with Navy personnel concerned with command and control, ranging from instructors at the Fleet Combat Training Center in San Diego to the commander of a carrier task group. Their comments supplied both the necessary background material for this research and a check on the realism of these taxonomies. Finally, the taxonomies reflect the basic concepts contained in the Naval warfare publications concerned with tactical command and control.

II CATEGORIES OF NAVY COMMAND AND CONTROL DECISIONS

The purpose of developing categories of command and control decisions is to allow some generalizations to be made about the many specific decisions encountered in the Navy. Almost every tactical decision has some aspect that makes it slightly different than others. However, many decisions have the same underlying structure and the same characteristics. For the purpose of designing and implementing decision aids, similar decisions should be aggregated into a relatively small number of categories.

There are far too many individual decisions for us to characterize each one, although the framework discussed in this report can be used to do so. This would mean that each time we identified a new decision, we would have to determine its characteristics and match them to the characteristics of available decision aids. By defining decision categories and determining the range of characteristics for all decisions in each category, we can determine the characteristics of an aid appropriate to a specific decision by identifying the category in which it belongs. Decision categories also help us identify multi-purpose decision aids that can be applied to a variety of specific decisions.

It is sometimes difficult to distinguish between the decision <u>categories</u> described in this section and the decision <u>characteristics</u> described in the following section. For instance, one way that we could categorize tactical decisions is by their analytical characteristics. However, for the purposes of our research a decision category is defined by the decision-making functions and organizations found in the Navy, while decision characteristics are defined by analytical properties that are common to all decisions. Thus, if this research were redirected to decision-making in an organization other than the Navy, it would be necessary to define a new set of decision categories, but the decision characteristics would remain basically unchanged. This distinction between decision categories and characteristics

allows us to classify a particular tactical decision by the way it fits into the general pattern of management activity in the Navy, and then translate it into a general set of characteristics that can be used to determine appropriate decision aids.

Criteria for Defining Decision Categories

Several criteria have been used to guide the definition of the decision categories used in this research. Some of these criteria would be applicable to any taxonomy, while others deal with the relationship between the decision categories and the set of analytic characteristics.

The definition of each decision category should be sufficiently clear and detailed either to include or exclude any specific decision. Unfortunately, this criterion is difficult to satisfy. No matter how clearly the distinction is drawn between different types of decisions, there are always borderline cases. Perhaps a better criterion would be that decision categories be sufficiently well-differentiated to minimize the difficulty in classifying most decisions. In other words, the decision categories should be mutually exclusive and should be chosen in such a way that relatively few decisions lie near the boundaries between categories. Thus, rather than relying on the definition of a single category, we may find it necessary to ask questions like, "Is this particular decision more like those in category A or those in category B?"

In addition, it is important that the decision categories be collectively exhaustive. In other words, there should be a category for each specific command and control decision. It is difficult to be sure that this criterion is satisfied, especially when a large number of specific decision categories are used. Consequently, we have attempted to define the decision categories in relatively broad, comprehensive terms.

A suitable level of detail in the taxonomy of decision categories represents a balance between the number of assessments required to characterize all categories and the difficulties inherent in making these assessments. The categories should be chosen to avoid two extremes: a large number of very specific categories, each relevant to only a few decisions; and a few highly

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aggregated and over-simplified categories that are difficult to relate to specific decisions. The taxonomy described here contains about 200 decision categories, each of which can be illustrated by a specific decision.

Another criterion for the decision categories is that each contain sufficiently similar decisions to allow a common assessment of their characteristics. The categories described here are not sufficiently detailed to preclude decisions with different characteristics from falling into the same category. However, it is possible to identify characteristics representative of the majority of decisions in each category. (See Section IV.) The range of possible decision characteristics in each category could be minimized by subdividing the categories described here. Some ways to accomplish this are described at the end of this section. However, increasing the number of decision categories will make it difficult to draw conclusions about the nature of general-purpose decision aids, and it makes the taxonomy too large to be useful. Some variation in decision characteristics is needed in each category to avoid a taxonomy that is too specific and too large.

The Dimensions of Command and Control Decisions

There are a variety of ways to categorize Navy tactical decisions. For instance, a decision can be categorized by the level of command at which it is made, by the type of warfare involved, or by the function performed by the decision. Each way of categorizing decisions can be considered to be one dimension in a multi-dimensional taxonomy of decision categories.

Subdividing command and control decisions along several dimensions simplifies the process of defining individual decision categories. Rather than a separate definition for each category, it is sufficient to define a relatively small number of descriptors along each dimension. These can then be combined to form a larger number of specific decision categories. In addition, the use of several dimensions makes it easier to keep track of the resulting decision categories.

The taxonomy of decision categories developed during this research is specified by four dimensions, shown in Table 1. The four dimensions are: the level of command at which a decision is made; the type of warfare for which it is made, the decision function (i.e., the generic task accomplished by the decision); and the decision context (i.e., whether the decision is made in a planning, execution, or emergency environment). Each of these dimensions is specified by several descriptors that can be combined to produce individual decision categories. The dimensions themselves can be categorized in more detail than is shown in Table 1. However, a meaningful characterization of each decision category is possible with the current level of detail.

Figure 2 shows two ways of visualizing the taxonomy of decision categories. For the sake of clarity, only two of the four dimensions of the taxonomy are shown in Figure 2. The dimensions represented are the level of command and the decision context.

Figure 2a shows each dimension as an axis in a two-dimensional space. Therefore, a given category is represented as a point in the space. The example shown is for a decision at the "Unit" level of command, and in the "Planning" decision context. The obvious problem with this representation is the difficulty of visualizing the four-dimensional space required to represent the taxonomy fully. Therefore, while it is not useful for practical purposes, this representation provides insight on a conceptual level. It points out that each category has several "adjacent" categories that differ from it in only one dimension. It is possible to test the extent to which decisions in each category can be uniquely characterized by comparing the characteristics of decisions in adjacent categories.

Figure 2b shows another way to visualize a multi-dimensional taxonomy of decision categories. In Figure 2b, the decision categories are represented by the endpoints of a tree (i.e., a hierarchy), where each dimension is represented by a different level of nodes in the tree. This representation is not as compact as Figure 2a, and does not identify all the adjacent

TABLE 1

DIMENSIONS OF THE TAXONOMY OF DECISION CATEGORIES

A. Level of Command

1. Fleet
2. Task Force
3. Unit

B. Type of Warfare

1. Air Strike
2. Anti-Aircraft (AAW)
3. Anti-Submarine (ASW)
4. Amphibious
5. Surface
6. Intelligence
7. Logistics
8. Other Support Activities

C. Decision Function

1. Specify Subobjectives or Subtasks
2. Select Assets to Accomplish Each Subobjective or Subtask
3. Position Forces and Specify Timing

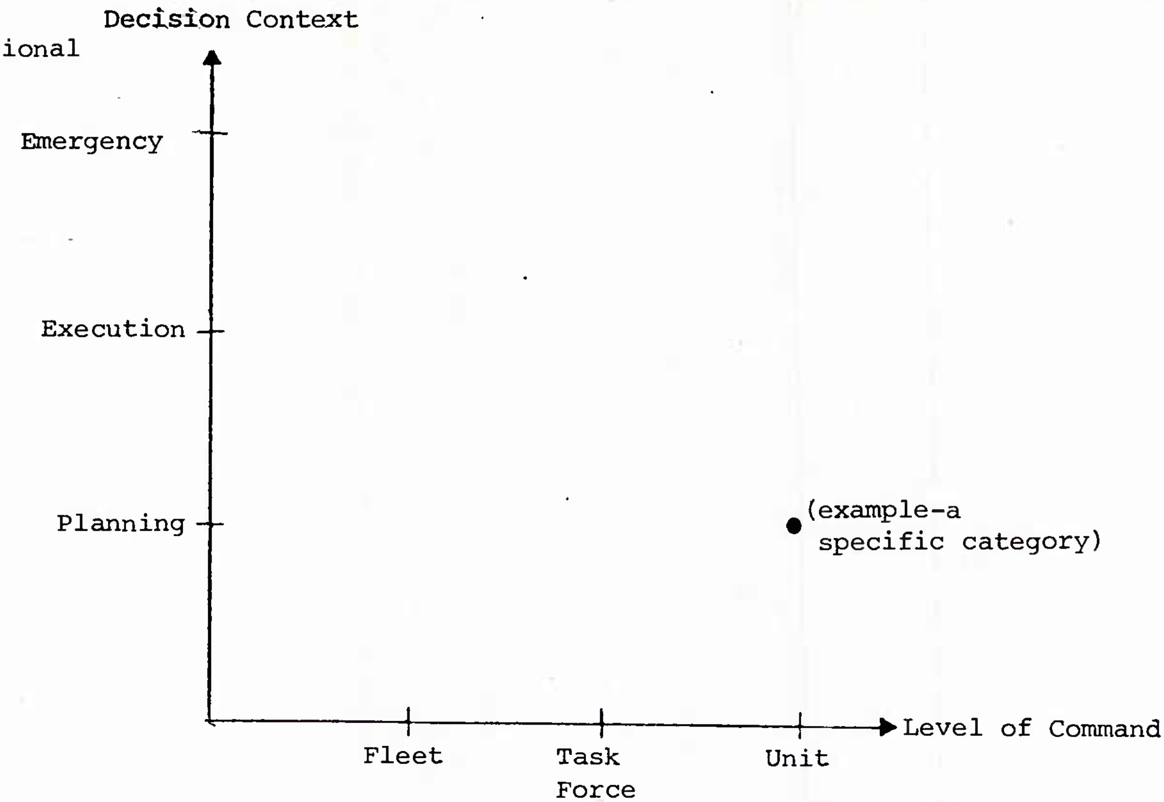
D. Decision Context

1. Planning
2. Execution
3. Emergency

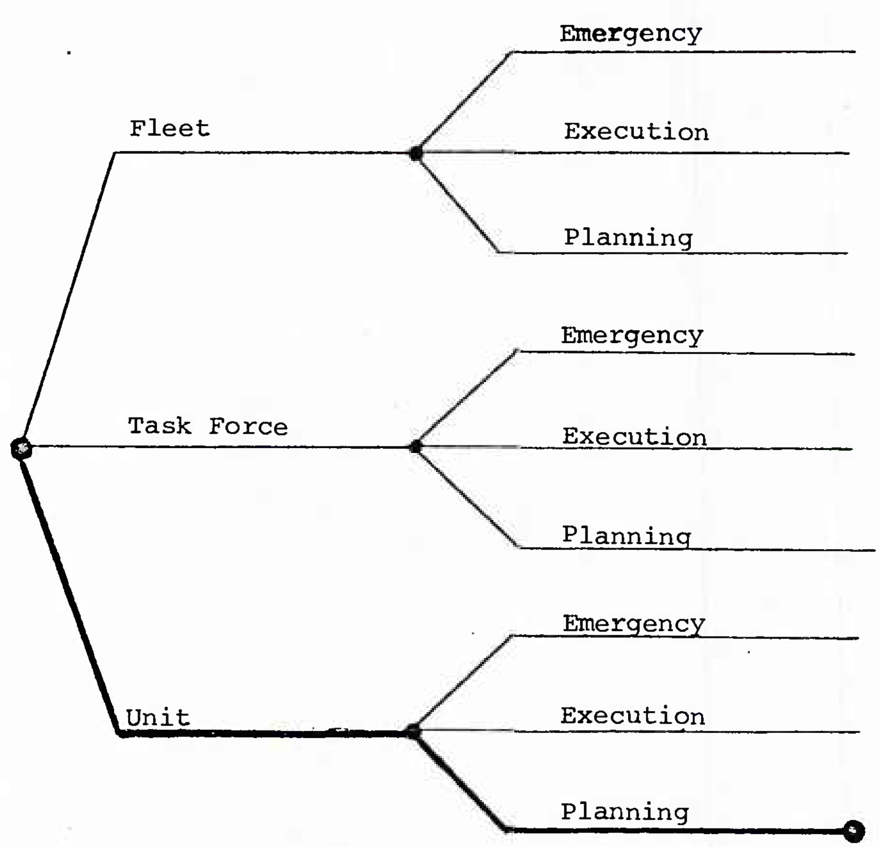
FIGURE 2

TWO WAYS TO VISUALIZE THE TAXONOMY OF DECISION CATEGORIES

(a) A Multi-Dimensional Space



(b) A Tree



categories. However, it overcomes the problem of visualizing multi-dimensional spaces and provides a straightforward way to enumerate the decision categories. One advantage to this method of visualizing the taxonomy of decision categories is that it may enable us to eliminate portions of the tree if some combinations of the decision dimensions are incompatible or unimportant. This kind of "tree pruning" has not been used in the taxonomy presented in this report, although there appear to be some decision categories that are less important than others.

Description of the Taxonomy Dimensions

The remainder of this section describes the four dimensions of the taxonomy of decision categories.

The first dimension of the taxonomy is the level of command at which a decision is made. Differentiating between decisions made at various levels of command allows us to explore the differences among decision aids appropriate for each level. The three levels of command shown in Table 1 are relatively broad groupings, but are adequate for our purposes. For instance, fleet command includes all levels of command not specific to a task force, including administrative commands. Task group and type commanders are considered part of the task force command level. Unit commanders include ship captains and their staffs (operations officer, tactical action officer, weapons coordinators, etc.) and air wing commanders.

The second dimension of the taxonomy is the type of warfare for which a decision is made. It is apparent that the characteristics of decisions associated with various types of warfare are significantly different. For instance, uncertainty is a much more significant factor in anti-submarine warfare than in anti-aircraft warfare.

Some tactical decisions may require a commander to consider several types of warfare simultaneously. It may be possible to define major decision categories for various types of combined warfare, but this level of detail

probably is not necessary. Navy officers tend to break down problems according to the types of warfare involved and assign each sub-problem to a separate command or staff officer. Attempts to build decision aids for several types of warfare (such as the NTDS) have not been successful, primarily because of the different characteristics of decisions associated with each type of warfare. Thus, several distinct decision aids may be appropriate to deal with different types of warfare, even if they are all used by the same decision-maker and supported by the same data processing equipment. In any case, the requirements for aids to support decisions involving more than one type of warfare can be determined by aggregating the desired aid characteristics associated with each type of warfare.

The third dimension of the taxonomy describes the basic <u>decision function</u>: the generic task accomplished by the decision. These functions are implicit in Navy doctrine and publications, but they have not been spelled out as clearly as the other dimensions of the taxonomy. The three decision functions are: the specification of subobjectives or subtasks, the selection of assets to accomplish each subobjective or subtask, and the positioning of forces and timing of operations.

It can be argued that the first decision function, specifying subobjectives, is not a decision but a specification of values. However, this category does not refer to a commander's objectives but to the objectives he specifies for subordinate commands. By specifying subobjectives, a commander is telling his forces what he wants them to accomplish. To define subobjectives, the commander must interpret the directives and orders that are received from higher command, and break them down into a more specific and operational set of subtasks. This breakdown requires some of the most important decisions faced by any Navy officer. It includes decisions such as whether an enemy force should be engaged, the level of resources that should be expended to destroy it, and when the operation should be completed.

The second major decision function is the selection of assets to accomplish each subobjective or subtask. This set of decisions determines how

a commander's forces will accomplish the objectives that he has set for them. It requires the decision-maker to assess the capabilities of his forces, weigh them against those of the enemy, and specify subsets of his forces capable of accomplishing each task.

It appears that more time and effort is devoted to the selection of assets than the specification of subobjectives, especially during the planning of operations. Thus, decision aids that help a commander identify the best assets to use for each objective may be particularly useful. The importance of this decision function suggests that it be specified in more detail. One way to do this is by defining a separate decision category for each type of asset. For example, this category could be subdivided into decisions dealing with the assignment of staff members, subordinate commands, ship and aircraft units, command and control facilities, and support units to various objectives. However, this additional detail does not appear to be necessary for an adequate characterization of command and control decisions.

The third decision function deals with the positioning of forces and timing of operations. Decisions in this category specify where and when actions will be undertaken to achieve a commander's objectives. Positioning and timing decisions must be distinguished from objectives expressed in terms of position or time. Decisions concerning positioning and timing specify formations and movements that are controlled primarily by the decision-maker. Objectives expressed in terms of position or time specify desired outcomes to be achieved in the face of enemy resistance or an uncertain environment. For example, a decision to attack an enemy force at dawn deals with timing, but an order to destroy the force within three days specifies an objective. Similarly, if a commander decides that his forces should establish a blockade in a particular location, he is specifying an objective for his forces, but the movement of his ships and aircraft in preparation for the blockade requires a positioning decision.

The fourth dimension of the taxonomy deals with the <u>decision context</u>. The three major categories along this dimension are: planning, execution,

and emergency. As the decision process progresses along this dimension, individual decisions tend to become adaptations or refinements of those made previously. Thus, the same decision may be made and remade several times, as it is first considered during the planning phase, revised during execution, and finally reconsidered if an emergency arises.

Planning decisions are distinguished from execution and emergency decisions by the fact that they occur prior to the implementation of operations specified in the plan. Planning decisions deal with future operations, and must therefore be made without full knowledge of what may occur as the operations are carried out. Planning requires contingent decision-making; operations will be conducted according to plan if certain assumptions prove to be true. On the other hand, execution decisions are made during the course of an operation with considerably more information about the status of forces and the physical environment. Execution decisions are adaptations or extensions of planned operations. Emergency decisions are made in reaction to an event that has a significant impact on the extent to which the commander's objectives can be achieved. Usually the event that triggers an emergency has not been adequately considered during the planning phase and requires a set of decisions for which the plan provides relatively little guidance. While the boundaries between the three decision contexts are ambiguous, it is clear that decisions in each category have different characteristics and that different types of decision aids are appropriate.

A possible fourth category along this dimension contains decisions that are made to modify Navy procedures as a result of an evaluation of previous operations. While these decisions are obviously important for determining the manner in which command and control decisions are made, they cannot really be classified as tactical decisions, and have been excluded from this taxonomy.

Table 2 presents examples of specific decisions in some of the decision categories. The types of warfare represented in the table are air strike, anti-aircraft warfare, and anti-submarine warfare. A complete description of each decision in Table 2 would require an identification of all the

TABLE 2

EXAMPLES OF SPECIFIC DECISION ALTERNATIVES IN SOME OF THE DECISION CATEGORIES

LEVEL OF COMMAND
- TYPE OF WARFARE
  - DECISION FUNCTION
    - DECISION CONTEXT

1. Fleet
   1. Air Strike
      1. Objectives
         1. Planning - Defend an ally by attacking enemy forces.
         2. Execution - Sink enemy missile boats.
         3. Emergency - Attack to support evacuation of own civilians from an ally's territory.
      2. Assets
         1. Planning - Assign two aircraft carriers to task force.
         2. Execution - Transfer control of air units to task force.
         3. Emergency - Assign additional VF squadron to task force in response to massive enemy reinforcement.
      3. Positioning & Timing
         1. Planning - Position one CV within striking range after 1 February.
         2. Execution - Accelerate attacks.
         3. Emergency - Delay attacks until UN debates are completed.
   2. Anti-Aircraft (AAW)
      1. Objectives
         1. Planning - Defend ally's territory from air attack.
         2. Execution - Concentrate air defenses around ally's cities.
         3. Emergency - Supply air cover for an evacuation of civilians.
      2. Assets
         1. Planning - Assign four VF squadrons to the task force for defense of an ally.
         2. Execution - Transfer control of air units to task force.
         3. Emergency - Use two VF squadrons from task force to supply air cover for evacuation.
      3. Positioning & Timing
         1. Planning - Keep carriers beyond range of enemy aircraft.
         2. Execution - Be in position to establish air blockade on 1 February.
         3. Emergency - Reposition task force air defenses to counter enemy air threat.

TABLE 2 (Cont'd.)

LEVEL OF COMMAND

TYPE OF WARFARE

DECISION FUNCTION

DECISION CONTEXT

1. Fleet
   3. Anti-Submarine (ASW)
      1. Objectives
         1. Planning - Defend convoy from enemy submarine attack.
         2. Execution - Discontinue search for submarines far from the convoy.
         3. Emergency - Protect damaged cruiser while it returns to base.
      2. Assets
         1. Planning - Assign control of P3 aircraft to task force during convoy operations.
         2. Execution - Transfer additional S3 aircraft to task force.
         3. Emergency - Detach two destroyers to escort damaged cruiser.
      3. Positioning & Timing
         1. Planning - Establish convoy route to avoid enemy submarine patrol areas.
         2. Execution - Divert convoy and escort to avoid new submarine contact.
         3. Emergency - Reposition reserve forces to provide protection for damaged cruiser.
2. Task Force
   1. Air Strike
      1. Objectives
         1. Planning - Destroy enemy aircraft and support facilities.
         2. Execution - Destroy SAM sites before continuing attacks on air field.
         3. Emergency - Sink enemy missile boat located near carrier.
      2. Assets
         1. Planning - Attack enemy aircraft and support facilities with A7's and A6's.
         2. Execution - Switch A7's and A6's to stand-off weapons.
         3. Emergency - Divert A7's to attack missile boat.
      3. Positioning & Timing
         1. Planning - Launch first strike at 0800.
         2. Execution - Move closer to minimize aircraft fuel consumption during transit to attack.
         3. Emergency - Delay next strike until missile boat is sunk.

TABLE 2 (Cont'd.)

LEVEL OF COMMAND

TYPE OF WARFARE

DECISION FUNCTION

DECISION CONTEXT

2. Task Force
   2. Anti-Aircraft (AAW)
      1. Objectives
         1. Planning - Defend carrier from air attack.
         2. Execution - Provide air cover for returning attack aircraft.
         3. Emergency - Destroy enemy bombers threatening task force.
      2. Assets
         1. Planning - Use F14's for CAP.
         2. Execution - Intercept incoming air raid with deck launched interceptors.
         3. Emergency - Direct CAP to attack enemy bomber.
      3. Positioning & Timing
         1. Planning - Station CAP on either side of threat axis.
         2. Execution - Reposition CAP to provide cover for returning attack aircraft.
         3. Emergency - Delay attack on enemy bombers until warning is issued.
   3. Anti-Submarine (ASW)
      1. Objectives
         1. Planning - Defend carrier from submarine attack.
         2. Execution - Discontinue search for submarine and return to station.
         3. Emergency - Locate submarine detected near aircraft carrier.
      2. Assets
         1. Planning - Use P3 aircraft for long-range ASW screen.
         2. Execution - Assign ASW helicopters to investigate submarine contact.
         3. Emergency - Launch S3 to attack submarine located near carrier.
      3. Positioning & Timing
         1. Planning - Position a destroyer behind the carrier.
         2. Execution - Move ASW screen based on submarine detections.
         3. Emergency - Launch an immediate attack on submarine to prevent it from firing at carrier.

TABLE 2 (Cont'd)

LEVEL OF COMMAND

TYPE OF WARFARE

DECISION FUNCTION

DECISION CONTEXT

3. Unit
    1. Air Strike
        1. Objectives
            1. Planning - Suppress SAM defenses while main force attacks air field.
            2. Execution - Concentrate on destroying fuel dump.
            3. Emergency - Provide cover for downed pilot until helicopter arrives.
        2. Assets
            1. Planning - Attack SAM sites with first group of aircraft.
            2. Execution - Divert second wave of aircraft to attack fuel dump.
            3. Emergency - Assign an A6 to cover downed pilot.
        3. Positioning & Timing
            1. Planning - Conduct bombing runs from north to south.
            2. Execution - Attack without waiting for fighter escort to arrive.
            3. Emergency - Make one pass and return to avoid running out of fuel.
    2. Anti-Aircraft (AAW)
        1. Objectives
            1. Planning - Shoot first at aircraft attacking carrier.
            2. Execution - Intercept unidentified target and identify before firing.
            3. Emergency - Provide air defense for damaged ship.
        2. Assets
            1. Planning - Intercept enemy aircraft with CAP first, and then missiles.
            2. Execution - Assign CAP to identify target.
            3. Emergency - Use missiles to defend carrier while CAP supplies cover for damaged ship.
        3. Positioning & Timing
            1. Planning - Position ship near center of AAW sector.
            2. Execution - Delay firing to improve accuracy.
            3. Emergency - Reposition CAP to provide air defense for a damaged ship.

TABLE 2 (Cont'd.)

<u>LEVEL OF COMMAND</u>

<u>TYPE OF WARFARE</u>

<u>DECISION FUNCTION</u>

<u>DECISION CONTEXT</u>

3. Unit
    3. Anti-Submarine (ASW)
        1. Objectives
            1. Planning - Attack any submarine entering assigned sector.
            2. Execution - Identify submarine contact.
            3. Emergency - Take evasive action to avoid submarine attack.
        2. Assets
            1. Planning - Assign best operators to sonar.
            2. Execution - Assign S3 under ship control to locate contact.
            3. Emergency - Assume control from damaged destroyer.
        3. Positioning & Timing
            1. Planning - Position ship near aircraft carrier.
            2. Execution - Position ship near aircraft contact with submarine.
            3. Emergency - Move into position to defend a damaged ship.

available alternatives. For brevity, only one alternative (e.g., the one chosen by the decision-maker) is listed for each decision. The examples in Table 2 serve to demonstrate that the taxonomy of decision categories can be translated into specific tactical command and control decisions.

It should be noted that each of the examples in Table 2 that deal with an emergency decision requires the specification of a causal event. For example, the reassignment of forces to defend a damaged ship is an emergency decision necessitated by the extent that damaged the ship. In contrast, decisions made during the execution of a plan are logical consequences of the plan, generally guided by information contained in the plan.

Additional dimensions could be included in the taxonomy of decision categories. One possible dimension deals with the decision process -- the manner in which a commander chooses to assign decision-making tasks to his staff and subordinate commanders. In other words, this dimension deals with a commander's style of decision-making. Three descriptors along this dimension are: a direct decision made by the commander, decision-making by negation (i.e., partially delegated decision-making), and delegated decisions. Direct decisions are those made by the commanding officer based on information, alternatives, and suggestions prepared by his staff and subordinate commanders. Decision by negation refers to the process by which a commander instructs his staff to reach a decision, but reserves the right to intervene and change their decision. This decision process typically requires the staff to formulate a course of action and present it to the commander for his approval. Delegated decisions involve a transfer of decision-making responsibility from one level of command to another, or from a commander to his staff.

The decision process has not been included as one of the dimensions of the taxonomy of decision categories because its primary effect is to shift decision-making activity from one individual or organization to another. This transfer does not affect the basic chacteristics of the decision, so there is insufficient justification to develop separate decision categories for the decision process.

Another possible dimension that could be added to the taxcnomy is the level of conflict that exists when a decision is made. Four representative descriptors along this dimension are: a peaceful or cold-war situation, a limited-scale conflict against a minor adversary, a major non-nuclear conflict against a powerful adversary, and unlimited nuclear war. The level of conflict can influence several decision characteristics, including the number of decision strategies and significant factors, and the frequency with which a decision occurs. However, it is doubtful that a decision aid would be acceptable to the Navy unless it were capable of providing assistance under difficult combat conditions. Thus, an aid should be designed with characteristics that are adequate for both high and low levels of conflict. This can be accomplished by assessing the characteristics of the more difficult decisions in each category (i.e., moderate to high levels of conflict). This approach was taken in the assessments described in Section IV.

An additional aspect of command and control decisions that can affect their characteristics is the nature of the decision-maker. Senior decision-makers in the Navy exhibit a variety of management and problem-solving styles, reflecting their differing backgrounds, experience, and training. Some officers prefer to deal with summary-level information when making a decision, while others are willing to analyze a problem in more detail. Similarly, some officers tend to rely on qualitative structuring of a decision, while others place more emphasis on quantitative logic. Different individuals can assign different characteristics to the same decision, depending on how they choose to think about it. For instance, the number of decision strategies and the importance of contingent decisions depends in part on the range of alternatives a decision-maker is willing to consider.

The dependence of a decision's characteristics on the approach taken by a decision-maker indicates that we could define another dimension for the taxonomy of decision categories (or a new taxonomy) that describes his approach to analyzing and making decisions. Descriptors along this dimension would specify the amount of detail and quantitative logic that the decision-maker normally considers in making a decision. However, this expansion of the taxonomy is inappropriate for two reasons. First, decision aids

are designed for use by many officers, and we do not know an individual decision-maker's characteristics at the time an aid is designed. Secondly, several individuals may be involved in the decision-making process, and they may each take a different approach to the problem. If the characteristics of command and control decisions are conditioned on the nature of the decision-maker, it will be necessary to identify an average or typical individual in order to select appropriate general-purpose aids. The process of assessing the characteristics of command and control decisions can be simplified by making one set of assessments based on a typical decision-maker. This approach was used for the assessments described in Section IV.

III A TAXONOMY OF DECISION CHARACTERISTICS

This section presents a taxonomy of decision characteristics. The characteristics described here are based on analytical measures used in management science, decision analysis, and related fields, and are not specific to Navy command and control decisions. The purpose of the taxonomy is to provide a way to assess the analytic properties of any decision, including Navy command and control decisions.

Criteria for Defining the Characteristics of Decisions

The criteria used to select the characteristics contained in this taxonomy are similar to those used to select an appropriate set of attributes to describe the outcomes of a decision problem.[1] In other words, the set of characteristics should be complete, operational, and minimally redundant, as explained below.

The set of characteristics should be complete so that it deals adequately with all the important aspects of a decision. In other words, a specification of a complete set of decision characteristics should be sufficient to describe the basic nature of the decision. This criterion has been tested by applying the characteristics to a variety of decision categories and it appears they describe all important aspects of each decision.

The characteristics should also be operational. This means that they are defined in terms that are meaningful to the design and evaluation of decision aids. They should also be defined in terms that can be related to specific decisions.

It is very difficult to describe decision characteristics that do not overlap in some way. However, in order to keep the list of characteristics

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1. See "Decisions with Multiple Objectives: Preferences and Value Tradeoffs," by R.L. Keeney and H. Raiffa, John Wiley and Sons, 1976.

as short as possible, this redundancy should be minimized. Since we are not attempting to create a formal multiattribute value measure, it is not essential that all redundancy among the characteristics be eliminated. Thus, some pairs of characteristics included in the taxonomy deal with closely related aspects of a decision. The taxonomy is defined to cover all important aspects of decisions, with as few overlapping characteristics as possible.

Taxonomy of Decision Characteristics

Table 3 contains the taxonomy of decision characteristics. The sixteen characteristics are broken into four groups: stakes, complexity, information, and timing. For each characteristic, the following are presented in the table: characteristic number and title, technical measure, assessment measure, and assessment scale.

Two different measures have been developed for each characteristic. The first is labelled the technical measure. The technical measure attempts to define precisely the characteristic in terms of analytic concepts drawn from the field of management science.

Almost all of the technical measures are quantitative, and it is possible to assess the value of each for any decision. However, this assessment process could be very difficult and time-consuming, particularly if the assessor is not familiar with quantitative analysis. To circumvent this problem, a second measure has been developed for each characteristic. This is labeled the assessment measure. The assessment measure is an approximation to the technical measure, and is designed to allow for rapid assessment by a person who is not familiar with quantitative analysis. Each assessment measure has a corresponding assessment scale. In many cases the assessment measure is expressed numerically or in percentages. In these cases, the assessment scale is simply quantized into three to five intervals over the total span of the measure. In other cases, the assessment scale is qualitative: a set of three to five descriptive responses have been developed. During the assessment process, the accessor selects the most appropriate response for the decision being considered.

TABLE 3: TAXONOMY OF DECISION CHARACTERISTICS

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

A. STAKES

1. The Decision-maker's Resources

Equivalent force level controlled by the decision-maker

(Same)

(1) Single aircraft
(2) Single ship, not a high-value unit (e.g., cruiser or destroyer)
(3) Single ship, high-value unit (e.g., aircraft carrier)
(4) Task group
(5) Task force
(6) Fleet

2. The Importance of Decision to Decision-maker

The level of resources directly affected by the decision, divided by the decision-maker's resources

Importance of the decision relative to the other decisions made by the decision-maker over one year.

(1) 99th percentile of importance (i.e., top 1%)
(2) 90-99th percentile (top 10%)
(3) 50-90th percentile (more important than average)
(4) Less than 50th percentile (less important than average)

TABLE 3: TAXONOMY OF DECISION CHARACTERISTICS (Cont'd.)

GROUP

CHARACTERISTICS NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

B. COMPLEXITY

3. The Number of Decision Strategies

Number of decision strategies (i.e., contingent courses of action)

Number of alternatives available in the primary decision problem (i.e., first decision node in a decision tree)

(1) 2

(2) 3

(3) 4 to 6

(4) Greater than 6

4. The Number of Significant Factors

Number of factors (i.e., state variables) that could have a significant impact on the outcome

(Same)

(1) Less than 3

(2) 3 to 5

(3) 6 to 9

(4) 10 to 100

(5) Greater than 100

TABLE 3: TAXONOMY OF DECISION CHARACTERISTICS (Cont'd.)

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

5. The Number of Outcome Attributes

Minimum number of outcome variables (i.e., attributes) that must be considered to adequately represent outcomes

(Same)

(1) 1

(2) 2 to 3

(3) 4 to 6

(4) 7 to 10

(5) Greater than 10

6. Outcome Measurability

Percentage of outcome variables (attributes) requiring a subjective scale

(Same)

(1) 0%

(2) 1 to 10%

(3) 10 to 50%

(4) Greater than 50%

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

7. Contingent Decisions

The average or typical number of variables that must be resolved before the best alternative can be selected at any individual decision point

The importance of contingent planning in this situation

(1) Important - A major part of the decision at this point is to decide which conditional courses of action should be selected after preliminary uncertainties have been resolved.

(2) Relevant - Conditional courses of action must be considered, but are not as important as the immediate decision.

(3) Not Important - The decision can be made at this point, and will be executed without reference to the resolution of uncertainties.

8. Probabilistic Dependence

Average or typical number of variables upon which each uncertain factor or outcome variable depends directly

Average or typical number of variables that have a significant and direct impact on each outcome variable

(1) 0

(2) 1

(3) 2 to 3

(4) 4 to 5

(5) Greater than 5

TABLE 3: TAXONOMY OF DECISION CHARACTERISTIC (Cont'd.)

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

9. The Degree of Risk

The relative likelihoods of high-consequence events and expected events

Importance of low-probability, high-consequence events

(1) Little or no bearing on decision

(2) Some bearing on decision

(3) Important factor in making decision

(4) Dominating factor in making decision

10. Review and Approval

Extent of required review and approval

(Same)

(1) Firm decision

(2) Tentative decision, subject to review

(3) Recommendation

(4) Information for another decision-maker

11. Structural Uniqueness

Extent to which existing plans or procedures can be used to deal with the decision

(Same)

(1) A new approach must be formulated

(2) An old plan or procedure can be adapted to current problem

(3) An old plan or procedure can be used directly with minor changes

TABLE 3: TAXONOMY OF DECISION CHARACTERISTICS (Cont'd.)

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

C. INFORMATION

12. The Quantity of Information

Quantity of information pertaining to a decision received by a decision-maker and his staff, in terms of the number of bytes per day (or a Shannon information measure per unit time)

Number of messages related to decision received per day

(1) Less than 10

(2) 10 to 100

(3) Greater than 100

13. The Variability of Information Value

Sample variance of the value of incoming information

Percentage of messages that are significantly more valuable than the average

(1) 0 to 1%

(2) 1 to 10%

(3) More than 10%

14. The Reliability of Information Sources

Average degree of calibration of the information sources

Percentage of information sources considered reliable

(1) Less than 40%

(2) 40 to 60%

(3) 60 to 80%

(4) More than 80%

TABLE 3: TAXONOMY OF DECISION CHARACTERISTICS (Cont'd.)

GROUP

CHARACTERISTIC NUMBER AND TITLE

TECHNICAL MEASURE

ASSESSMENT MEASURE

ASSESSMENT SCALE

D. TIMING

15. The Time Available for the Decision

Time from recognition of a decision to the point where an action must be taken

(Same)

(1) Less than 1 minute
(2) 1 minute to 1 hour
(3) 1 hour to 1 day
(4) 1 day to 1 month
(5) Greater than 1 month

16. The Frequency of Decision

Mean time between recurrence of the decision

(Same)

(1) Less than 10 minutes
(2) 10 minutes to 10 hours
(3) 10 hours to 1 month
(4) 1 month to 1 year
(5) Greater than 1 year

It is important to note the relationship between the two measures. The technical measure provides the underlying definition of the characteristic. In general, it will not be assessed; its purpose is to provide definition, and to clarify any ambiguity that might arise. The assessment measure is a proxy for the technical measure, and is designed to allow for easy assessment. An attempt was made to retain a direct relationship between the assessment and the technical measure. In the most successful cases, the measures are in fact identical. However, in all cases it is possible to map each point on the assessment scale into a range of values of the technical measure. As an example, consider the measures for Characteristic 12, the quantity of information. The technical measure is in terms of bytes of information received per day, while the assessment measure is in terms of the number of messages received per day. If we assume an average length for each message, the number of messages received could be converted directly into the number of bytes received.

The remainder of this section discusses the development of the characteristics and their respective technical and assessment measures. The characteristics and their related measures are the result of several months of discussion and comparison. They have been selected from a large pool of suggestions, and several versions of the taxonomy were developed before the one presented here evolved. It is expected that further discussion and testing of new characteristics and measures will produce ways of modifying the present taxonomy to be simultaneously smaller in size and broader in scope. However, the taxonomy discussed here is sufficiently comprehensive and well-defined to allow a meaningful evaluation of decision aids.

A. Stakes

The first two characteristics deal with stakes, or the resources at risk in the decision. Unless significant resources are involved, it is unlikely that decision aids will be developed, or used if they are developed.

Characteristic 1, the decision-maker's resources, measures the total level of resources controlled by the decision-maker, rather than only those resources directly affected by the decision. Resources can be expressed in terms of any single measure that indicates the importance of decision'maker's span of control relative to that of the other decision-makers. If the Navy is to maximize the use of its resources, decision aids with a high unit cost (i.e., the cost of an individual aid) should be provided only to those decision-makers who control large levels of resources. Where the amount of resources involved is small, decision aids with a lower unit cost are appropriate. However, it may be appropriate for the Navy to spend large amounts to design and develop an aid with a low unit cost for a large class of decision-makers each of whom controls a relatively low level of resources. For example, an expensive development effort would be appropriate for an aid to be installed in all Navy aircraft as long as the unit cost of the aid is acceptable.

The technical and the assessment measures are the same for this characteristic. The measure is the "equivalent force-level controlled by the decision-maker." The measure is based on the assumption that it is possible to make value tradeoffs between different types of naval resources, and therefore to establish a single-valued measure of resources. These tradeoffs are generally subjective and depend on the resources and situation of the person making them. For this taxonomy, the tradeoffs should reflect general Navy policy and the values of the highest levels of command. Thus, we would expect the tradeoffs not to depend on the viewpoint of a particular decision-maker. Rather, they can be thought of as the long-term value of various resources to the Navy.

Since a universal set of tradeoffs among Navy resources does not exist, a different approach was used for assessing this characteristic. The assessment asks, "Which of the following resource levels is closest to being equivalent to the total level of resources controlled by the decision-maker?" Six responses are presented on the assessment scale, representing a range of resource levels from a single aircraft to an entire fleet. The assessor selects

the response such that a decision-maker controlling the stated level of resources has roughly the same level of forces under his control as the decision-maker making the specific decision being discussed.

Characteristic 2, the importance of the decision to the decision-maker, measures the stakes or resources "at risk" for a given decision. Whereas the previous characteristic measured a given decision-maker against other naval decision-makers, this characteristic measures one decision against other possible decisions an individual might face. This characteristic is related to the cost of using a decision aid. Cost is meant to include "soft costs" such as the use of staff time as well as "hard costs" such as computer time and resource utilization. We assume that the more important the decision is to the decision-maker the more resources he will be willing to invest in using a decision aid. For example, it is worthwhile for Navy personnel to undergo extensive training to operate an NTDS console, but it is doubtful that the same level of effort would be justified for an aid concerned with logistics.

The technical measure for this characteristic is the fraction of the decision-maker's resources directly affected by the decision. Since this measure is difficult to assess, the assessment measure for this characteristic attempts to capture directly the level of importance of the decision in a qualitative manner. The measure asks the assessor to rank the importance of the decision relative to all the other decisions made by the decision-maker in a one-year period. The assessment scale is quantized into four ranges: top one percent, top 10 percent, top 50 percent, and lower 50 percent.

It is possible to combine the two characteristics in this group into a single characteristic. Since Characteristic 1 measures resources and Characteristic 2 expresses importance as a percentage of the decision-maker's resources, the product of the two technical measures yields the level of resources involved in the decision. This derived characteristic could be termed the overall importance of the decision to the Navy. If we had to choose a single measurement of stakes, this combined characteristic would be the logical choice. However, we feel that by decomposing

stakes into the decision-maker's resources and the importance of the decision to the decision-makers we have separated the characteristics dealing with initial cost of an aid from those dealing with the cost of using an aid. This decomposition allows us to focus on two distinct characteristics with different implications for decision aid design.

B. Complexity

Complexity can be thought of as measuring the difficulty of capturing a decision problem in a model structure. Characteristics 3 through 11 represent attributes of decision problems that have implications for model structure.

It is no coincidence that we have defined more characteristics under complexity than in any other group. Complexity is one of the easier areas to quantify because it can be related to standard concepts of management science. Many references describe the attributes of a decision problem that make it more or less analytically tractable.[1]

Complexity has several direct implications for decision aid design. Clearly the hardware and processing time requirements for analyzing a complex decision will exceed those of a less complex decision. We would expect that hardware and processing time requirements grow as the problem becomes more complex. Of particular interest is the rate of growth. For example, some decision-making techniques grow linearly in the number of calculations required as decision variables are added to the problem, while other techniques grow in an exponential manner. The former situation is clearly preferable in a complex situation where new decision variables are created and added to the problem structure while an analysis is being carried out.

Even more than the overall level of complexity, the nature or type of complexity exhibited by a decision situation will influence decision-aid design. Generally speaking, if a high level of complexity is indicated by

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1. See for example, "Foundations of Decision Analysis," by R.A. Howard, "IEEE Transactions on Systems Science and Cybernetics," Volume SSC-4, No. 3, September, 1968; and Keeney and Raiffa, op. cit.

one of the characteristics, then the design of an appropriate decision aid will be strongly influenced by that characteristic. On the other hand, if a characteristic indicates only a moderate amount of complexity, that characteristic will have little or no influence on the specification of a desirable decision aid.

As a final prefatory note to the discussion of the characteristics in this group, it should be understood that the decision environment faced by a decision-maker depends strongly on his subjective view of it. That is, the definition of the environment depends on the decision-maker's perceptions and information. For example, the determination of whether a particular feature of the environment is important to the decision depends directly on the decision-maker's viewpoint. The feature may be of critical importance to one decision-maker, while another decision-maker faced with the same decision environment may choose to dismiss it as unimportant. One possible solution to this problem is to base assessments of complexity on the characteristics of decision-makers. These characteristics are impossible to assess unless we know the identity of the decision-maker, or at least a large amount of information about him. Therefore, in this research we have not explicitly considered the decision-maker's characteristics, but instead assume a "typical" decision-maker, given a level of command and a warfare type. When we speak below of making assessments, it is understood the assessments reflect the viewpoint of a typical decision-maker.

Characteristic 3, the first in this group, is <u>the number of decision strategies</u>. In the case of a simple decision problem with a single decision to be made among several alternatives (e.g., to attack or not to attack), a strategy is simply the choice of one alternative. For more complex decision problems, a strategy is a complete specification of the alternatives to be selected at each decision point, conditioned on the resolution of any uncertainty. For example, a simple sequential problem is represented by the following sequence: a commander decides whether to attack, the enemy either fights or retreats, the decision-maker pursues or stops action, and outcomes are evaluated. A decision strategy would be to attack, and then to pursue if the enemy retreats. Decision strategies specify decision rules

for all possible scenarios. In decision analytic terms, a strategy specifies the alternatives selected at each decision node in a decision tree. Formally, considering a decision problem in terms of strategies is called normal form analysis, as compared to the more common extensive form analysis.

The technical measure in this case simply counts the number of decision strategies. This enumeration of all contingent strategies was found, however, to be too time-consuming for use in the assessment process. Thus, the assessment measure was changed to consider only the first or primary decision. That is, only the first decision node in the decision tree is examined. If no contingent decisions are involved (i.e., the first node is in fact the only decision node in the decision tree) then the assessment measure and the technical measure will yield the same number. If contingencies are involved, this will not be reflected by the assessment measure. However, Characteristic 7 directly assesses whether contingent courses of action are available.

Characteristic 4, the number of significant factors, deals with factors that cannot be controlled the the decision-maker. These factors are usually characterized as uncertain (i.e., their value is not known exactly at the time of the decision). For example, the significant factors associated with a task force decision among alternative methods of neutralizing enemy air capability include: the strength of the enemy forces, the extent to which they could be reinforced, the involvement of other countries, and the effectiveness of attacks on enemy airfields. In decision analysis, factors such as these are termed state variables, and the uncertainty associated with them is described by probability distributions. Significant factors are those that cannot be dropped from consideration without causing major inaccuracies in an analysis. The technical and assessment measures are the same for this characteristic; they require a count of the significant factors.

The major implication of Characteristics 3 and 4 for decision-aid design is the effect that an increase in the number of decision strategies or factors has on the hardware and processing requirements of the aid.

The next two characteristics in this group deal with the variables used to describe the outcomes of a decision. Characteristic 5 is the

number of outcome attributes. For example, the outcome attributes associated with an air strike on an enemy airfield include the number of aircraft lost in the attack, the damage to enemy facilities and aircraft, and the capability of either side to launch another attack. The technical and assessment measures are both "the minimum number of outcome variables (i.e., attributes) that must be considered to adequately represent outcomes." The phrase "to adequately represent outcomes" means that we are seeking a set of such that removal of any attribute seriously impairs adequate description of the full range of outcomes being considered. The word "minimum" indicates we are seeking the smallest possible set. Thus, candidate attributes should be aggregated to the greatest possible extent, subject to the constraint that the resulting set can fully represent the outcomes.

In some decision problems there will be only one outcome variable, but often more than one is required. The number of outcome variables will generally provide a measure of the complexity of the value tradeoffs required; the more attributes, the greater is the effort required to construct a value function. Correspondingly, more attributes will require greater processing capabilities for a decision aid.

Outcome measurability, Characteristic 6, examines the need for subjective scales to measure outcome variables. Many outcome variables have obvious physical scales, such as the number of ships destroyed. However, a decision may involve attributes for which no obvious physical measure exists. Examples of such attributes are morale and political reaction. These attributes may represent important aspects of the decision problem, and often cannot be ignored. If such an attribute is important, the decision-maker must assess it on a subjective scale. For example, it may be necessary to identify possible levels of political reaction to a military action, and balance them against other attributes. This calls for a decision aid that can accept subjective scales, and assist in the necessary assessments. Also, since the appropriate subjective scales will often be different for each decision and decision-maker, it will be necessary for the aid to accept new outcome variables and scales. This suggests an interactive aid would be appropriate.

Both the technical and assessment measures in this case are defined as "the percentage of outcome variables (attributes) requiring a subjective scale."

The next two characteristics measure the degree of interconnection among the major variables of a decision problem.

The first is Characteristic 7, contingent decisions. This characteristic measures the degree to which decisions depend on uncertain factors. In many decision problems, strategies can be conditioned on the resolution of various uncertainties. For example, a strategy of attacking if the weather is good can lead to two courses of action depending on the weather. This strategy includes two unconditioned alternatives: attacking and not attacking. In more complex decision situations, there may be many sets of unconditional alternatives contained in a single strategy.

The technical measure is the average or typical number of variables that must be resolved before the best alternative can be selected at any individual decision point. This measure gauges the extent to which the actual course of action will depend on uncertain events and the extent to which the decision should be delayed until additional information is gathered.

This technical measure was found to be very difficult to assess, as it involved examining all of the available sets of alternatives. The assessment measure is qualitative, and seeks simply to indicate whether the decision involves contingent planning. The measure asks the question, "Is contingent planning important in this situation?" As shown in Table 3, the responses are: (1) important - a major part of the decision at this point is to decide which conditional courses of action should be selected after the preliminary uncertainties have been resolved; (2) relevant - conditional courses of action must be considered, but are not as important as the immediate decision; and (3) not important - the decision can be made at this point, and will be executed without reference to the resolution of uncertainties.

The characterization of a decision situation as contingent is important to the design of an appropriate decision aid. The addition of conditioning factors will increase aid hardware and processing-time requirements, often causing exponential growth in the problem size. Also, contingent situations require an aid that can monitor and update information about the decision environment, and indicate which alternative should be chosen on the basis of this information.

Characteristic 8, probabilistic dependence, is similar to the previous characteristic, except that it focuses on the dependencies among uncertain variables, rather than on the dependence of decisions on these variables. In decision analytic terms, this characteristic measures the average number of conditioning variables for each uncertainty. In other words, what is the average number of uncertain variables whose values must be known in order to assess the probability distribution for an uncertain quantity? The technical measure directly assesses this number. However, in order to simplify the assessment process, the question is asked only for outcome variables. That is, the assessment measure is the average or typical number of uncertain factors that have a significant and direct impact on each outcome variable. For example, the number of aircraft lost in an airstrike could depend on the size and readiness of the enemy defensive forces, the weather during the strike, and the possible intervention of another country.

As in the contingent-decisions case, the addition of conditioning variables can substantially increase decision aid hardware and processing-time requirements.

A single measure of interconnection, which could replace Characteristics 7 and 8, was considered but rejected as too technical. This alternative measure is based on the concept of influence diagrams,[1] which depict schematically the interrelationships between decisions and uncertainties.

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1. See "Development of Automated Aids for Decision Analysis," by Miller, Merkhofer, Howard, Matheson, and Rice, SRI Technical Report 3309, 1976.

The measure is defined as the ratio of the number of arrows in the influence diagram to the number of nodes. This indicates the degree of interconnection of the variables. A low ratio, indicating relatively few interconnections, leads to a model that has relatively low date requirements, and is easy to manipulate. On the other hand, a high ratio indicates a large number of interconnections. Heavy interconnection requires substantial amounts of data, analytic effort, and computing resources.

Another feature of a decision problem that can add to its complexity is <u>the degree of risk</u> involved in the decision. This is measured by Characteristic 9. Risky decisions generally require more analysis than do more routine decisions, and often require a substantially different type of analysis.

A risky decision is one that involves outcomes with low probabilities and very significant consequences. The most common decision of this type deals with a low probability of high losses (i.e., for a given decision alternative, a very undesirable outcome is unlikely but possible). This type of situation is in contrast to one in which the range of possible outcomes is limited.

For example, a task force commander might estimate that the worst possible outcome that could result in a particular situation is the loss of one ship. In another situation, he might feel that if the worst outcome occurred, his actions could lead to the commencement of a nuclear war. The latter situation, where a small probability of a high loss exists, is fundamentally different from the former situation.

The development of measures of degree of risk proved to be particularly difficult. Several candidate definitions for both the technical and assessment measures were proposed, examined, and tested. Debate over the relative merits of the various measures led to the final selection of the two measures presented here.

The technical measure is the relative likelihoods of high consequence events and expected events. Typically, this is specified by the "moment of kurtosis," the ratio of the fourth central moment (kurtosis) to the square

of the variance of the distribution of possible outcomes. This measures the length of the "tails" of the distribution, and indicates the relative likelihood of high-consequence events. A large ratio, (i.e., longer tails), indicates that such events are important and should be included in the analysis. Although this technical measure can be specified rigorously, it is very difficult to assess. As a result, the assessment measure is completely qualitative. The measure is simply "the importance of low-probability, high-consequence events." The four responses are: (1) little or no bearing on decision; (2) some bearing on decision; (3) important factor in making decision; and (4) dominating factor in making decision. This measure is relatively straightforward to assess.

The degree of risk has several implications for decision-aid design. Given the emphasis on assessing probabilities in risky situations, it is apparent that the ability of the aid to deal with uncertainty is desirable. In particular, the aid should be able to work with the small "rare event" probabilities that characterize risky situations. Often this will be accomplished by decomposing low-probability events into a set of other events, for which probability assessments are less difficult. Also, the aid may be called upon to deal with risk aversion, in the form of risk-averse utility functions. Finally, another desirable feature for decision aids in risky situations is a "devil's advocate" capability. This refers to the ability of the aid to check plans to ensure the inclusion of relevant low-probability, high-consequence events.

The organizational environment of the decision-maker can also add to the complexity of a decision. One aspect of organizational environment is considered by Characteristic 10, review and approval. The degree to which a decision is subject to modification by other commands strongly influences a decision-maker's communication and documentation requirements. This in turn has implications for the communications capabilities of his decision aids. Also, if a decision will be reviewed, it is desirable that the aid document and summarize the data and the decision logic.

The technical and assessment measures are the same in this case: "the extent of required review and approval." Four levels of review and approval have been identified by Brown and Ulvila.[1] They are: (1) a firm decision where no review is required; (2) a tentative decision that will be reviewed by a higher level of command; (3) a recommendation where a decision strategy is selected but the decision will be analyzed again at a higher level of command; and (4) information for another decision-maker, where the choice of a decision strategy is left to another level of command. The distinctions between these categories are admittedly unclear, but we feel that they are adequate for guiding the development of decision aids.

The final characteristic of this group is Characteristic 11, <u>structural uniqueness</u>. This measures how well the decision fits into some pre-existing analytical framework. This effectively determines the amount of flexibility required of a decision aid. The technical and assessment measures are both "the extent to which existing plans or procedures can be used to deal with the decision." This measure is qualitative; we have not found a precise way to determine the fraction of an existing model that can be utilized. The assessment responses are: (1) a new approach must be formulated; (2) an old plan or procedure can be adapted to the current problem; and (3) an old plan or procedure can be used directly with minor changes.

C. Information

Appropriate treatment of information is probably the single most important attribute of a decision aid. This group of characteristics examines the nature of the information available to the decision-maker. The technical measures in this group are rather sophisticated, and are based on complex information theory and decision analysis concepts. Not surprisingly, we found it necessary to develop assessment measures that are simple approximations of the technical measures.

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1. See "Selecting Analytic Approaches for Decision Situations," Volumes 1 and 3, by Brown and Ulvila, Decisions and Designs, Inc. Technical Report TR 77-7-23, 1977.

The first characteristic in the group, Characteristic 12, is the quantity of information. It measures the rate at which information pertaining to the decision is received by the decision-maker. A decision aid that processes this information must be capable of sorting, analyzing, and storing data at a comparable rate.

The technical measure for this characteristic is the number of bytes per day of information pertaining to the decision received by the decision-maker and his staff. An alternative measure involves applying a Shannon information-theoretic measure which accounts for the likelihood that various pieces of information will be received. For assessment, a simpler measure is used. It is simply the number of messages received per day, where a message is taken to be on the average a one-page report.

There is obviously a problem with measuring only the volume of information, without considering its content. An intelligence report concerning enemy movements and a list of the items to replenish a ship's supplies are both considered to be one message, although the former may have many times the information value of the latter. Characteristic 13, the variability of information value addresses this point.

The technical measure developed for Characteristic 13 is "the sample variance of the value of incoming information." This is a highly conceptual measure, and is based on the decision analysis concept of the value of information. The value of information reflects the expected improvement in the decision-making process if the information is provided to the decision-maker. Given that a value of information could be computed for each incoming piece of information, the technical measure then calculates the variance over the resulting sample. A large variance indicates that the value of information varies greatly between the pieces of information being received.

Although the technical measure is well defined, it is very difficult to assess directly. Thus, the assessment of this characteristic calls for a subjective estimation of "the percentage of messages that are significantly more valuable than the average." Although the assessment measure

is imprecise, it approximates the technical measure, and reflects the main idea of the characteristic.

Characteristic 13 determines whether a decision aid should perform a "filtering" function. A high variability of information would call for an aid that has the capability to screen incoming data and select important information for review by the decision-maker. A special case of this is the ability of the aid to produce "alerts" -- to monitor information and react when a potentially important pattern is detected.

Another issue with respect to information is data reliability. Characteristic 14 is <u>the reliability of information sources</u>. The value of a piece of information to a decision-maker will strongly depend on his estimates of the reliability of the information source. For instance, it is typical for a ship's CIC to gain a reputation for producing accurate or inaccurate information, and for decision-makers on other ships to react accordingly.

The technical measure for this characteristic is the average degree of "calibration" of the information sources. One way of assessing calibration has been proposed by Morris.[1] The method compares the source's estimates of the probabilities of a set of events to the actual probabilities of the events, resulting in a calibration function for the source. Since this approach includes the probability of error when a source supplies information with a probability of zero or one, it is useful for both deterministic and probabilistic information. It can be extended to include situations where a source supplies data with qualifying statements to indicate the degree of uncertainty associated with the information. A source is well-calibrated if it correctly indicates the uncertainty associated with the information it supplied. Such a source is considered reliable, even if it cannot provide deterministic estimates or assessments.

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1. See "Bayesian Expert Resolution," by P.A. Morris, Ph.D. Dissertation, Department of Engineering-Economic Systems, Stanford University, 1971.

Again the technical measure used here is very difficult to assess, so the assessment measure is qualitative. Analogous to the assessment measure for Characteristic 13, it directly assesses the "percentage of information sources considered reliable."

If a decision-maker must integrate and use information from sources of unequal reliability, an aid that weights, interprets, or screens some of the incoming information may be useful. Such an aid would have to identify data sources, and alter the manner in which the data is used, based on the decision-maker's assessment of a source's reliability. Another desirable aid feature is the ability to store and recall the source of each piece of information. This allows a decision-maker to review the decision process and to distinguish the sources of the data. The more the reliability of information varies between sources, the more desirable this feature becomes.

D. Timing

The final group of decision characteristics deals broadly with timing considerations. These include the time available to make a decision and the frequency with which a decision occurs.

Characteristic 15 is the time available for the decision. This characteristic measures the time period typically available to analyze the situation and arrive at a firm decision. The implication for aid design is obvious: the time required to use the aid must be compatible with the time available for the decision. Of particular interest is whether the aid's response time is sufficiently low to make it useful in an emergency. For instance, an aid for AAW decisions must be capable of supplying the decision-maker with the necessary information in a few seconds.

The technical measure for this characteristic defines the time available as "the time from recognition of a decision to the point where an action must be taken." This is also used as the assessment measure.

Characteristic 16 is the frequency of decision. The technical and assessment measures are both stated as "the mean time between recurrence of the decision." This characteristic provides two types of information. It indicates whether the decision is one that requires a dedicated decision aid (i.e., one that does not perform several functions). It also indicates how much time is available to modify or update a decision aid based on its performance on the previous decision. For example, an aid for task force planning decisions could be designed with enough flexibility to allow the user to adapt it to each planning situation. However, this capability would not be useful for repetitive decisions made according to established procedures.

IV ASSESSING THE CHARACTERISTICS OF COMMAND AND CONTROL DECISIONS

In the previous section, an assessment measure and a corresponding assessment scale were developed for each member of the taxonomy of decision characteristics. In this section, the measures are applied to representative decisions drawn from the taxonomy of decision categories described in Section II.

The task of applying the assessment measures to a set of representative decisions was included in this research for three reasons. The first and most obvious is to demonstrate the ability of the taxonomy of decision characteristics to adequately describe the features of naval decisions. However, it should be noted that the task performed here was regarded as a "pilot-level" analysis. The resulting assessments are not meant to be definitive or final. They are only the tentative evaluations of one individual.

A second and perhaps more important purpose of the assessment task was its role in the development of both the taxonomy of decision categories and the taxonomy of decision characteristics. The assessment process was used iteratively to test and refine the taxonomies. It proved to be an integral part of the development of the assessment measures and scales.

A final purpose of carrying out the "pilot-level" assessments was to provide insight into the assessment process itself. It was felt that the experience gained could prove useful in the design of a procedure for a more comprehensive set of assessments, should one be called for in the future. Such a task should combine the estimates of a panel of experts on Navy command and control.

The Assessment Process

The assessment process described here was carried out by a small team over a period of approximately two months. The decision-maker was represented by a retired U.S. Navy operations officer, who was assisted in making assessments by two decision analysts. Since the assessments are based on the judgments of a single individual, they cannot be regarded as a representative sample. The assessment of definitive characteristics for various naval decisions was not a goal of the assessment task.

Various decision categories were selected for the assessment task. For a given category, the assessments were based largely on representative decisions such as those in Table 2. It was found that the assessment process was very difficult unless specific examples were considered explicitly. This indicates that the decision categories are not sufficiently detailed to remove all ambiguity in the decision characteristics. However, representative decisions were chosen to be typical of each category, and their characteristics resemble those of many decisions in the same category. The same assessment procedures would apply to more specific decision categories or to individual decisions.

The procedure called for the assessor to select the most appropriate response from the assessment scale for each of the decision characteristics. Since a major purpose of the assessment process was to aid in the modification of the decision characteristics and, in particular, the assessment measures, the task was highly iterative in nature. The list of assessment measures evolved as the process progressed. Thus, as the measures were modified, it was necessary to go back and reassess decision categories that had been considered earlier.

Among the final sixteen assessment measures, the method used to make the assessments and the difficulty involved varied widely. The simplest measures to assess were those that happened to correspond

directly to a dimension of the taxonomy of decision categories. Characteristic 1, the decision-maker's resources, can be determined directly from the level-of-command dimension of the category being assessed. Similarly, Characteristic 15, the time available for the decision, is determined by the decision-context dimension of the category. This does not indicate these characteristics are redundant. If the assessment measures were applied directly to decisions and not to decision categories, the two characteristics could not be automatically determined in this manner.

It was initially hoped that each assessment measure could be quantitative. In fact, the first set of assessment measures proposed was identical to the set of technical measures that existed at that time. It was quickly discovered, however, that many of the technical measures were very difficult to assess. The general trend as the assessment task proceeded was to make the assessment measures more qualitative and subjective, especially for the more abstract or theoretical characteristics.

The most quantitative assessment measures remaining appear in the "complexity" group. Characteristics 3, 4, and 5 (the number of decision strategies, the number of significant factors, and the number of outcome variables) are the most difficult and time-consuming to assess. Each call for the assessor to think explicitly about the structure of the decision problem. For these measures it is necessary to structure a decision to the point where all of the decision strategies, factors, and outcome variables can be identified.

Characteristics 6, 7, and 8 (outcome measureability, contingent decisions, and probabilistic dependence) are closely tied to the three preceeding characteristics. Once the decision structure has been examined and Characteristics 3, 4, and 5 assessed, Characteristics 6, 7, and 8 can be assessed relatively quickly. For example, Characteristic 6 is assessed by examining the list of outcome variables developed in assessing Characteristic 5, and determining which of the variables are subjective.

Most of the remaining assessment measures are qualitative. These measures do not involve any explicit enumeration, but call instead for subjective assessments of the general features of a decision. For example, this is the case for Characteristic 9, the degree of risk. A large number of quantitative assessment measures were tested, but each was found to be either too complex to assess, or to have serious technical deficiencies. The same situation occurred with respect to Characteristics 13 and 14 (the variability of information value and the reliability of information sources) in the "information" group.

In other cases, a qualitative assessment measure was the natural choice, because the technical measure was also qualitative. This is the case for Characteristic 10, review and approval, and Characteristic 11, structural uniqueness.

In total, the final set of measures were assessed for 36 of the 216 decision categories. The iterative nature of the process (i.e., the refinement of the characteristics as the assessments progressed) caused the assessments to be time-consuming. Now that the assessment measures have been tested and finalized, future assessments can be carried out more rapidly.

Results of the Assessment

Tables 4 and 5 present the results of the assessment process for the 36 representative decision categories. Table 4 contains the assessments for all air strike decisions, including all combinations of level of command, decision function, and decision context. Table 5 contains the assessments for all combinations of decision functions and decision context for ASW decisions at the task force (TFC) level of command. Each column in the tables represents one decision category. Each row corresponds to a decision characteristic, and the table entries are the assessment scale responses (see Table 3). For instance, in Table 4 the entry for the third row and the first column is "3." The third row corresponds to Characteristic 3, the number of decision strategies. The first column corresponds to the

TABLE 4: ASSESSMENTS FOR AIR STRIKE WARFARE

Table entries refer to assessment scale responses in Table 3.

Category / Characteristics	Strike																											
	Fleet									TFC									Unit									(Level of Command)
	O			A			P&T			O			A			P&T			O			A			P&T			(Decision Function)
	P	E	Em	P	E	Em	P	E	Em	P	E	Em	P	E	Em	P	E	Em	P	E	Em	P	E	Em	P	E	Em	(Decision Context)
1. DM's Resources	6	6	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	2	2	2	2	2	2	2	2	2	
2. Importance of Decision to DM	1	2	1	2	3	3	3	3	3	2	3	2	2	2	2	2	3	3	3	3	3	3	2	2	2	2	2	
3. # of Decision Strategies	3	2	2	2	2	2	2	3	1	2	2	2	2	3	3	2	2	1	2	1	2	2	1	3	1	1	1	
4. # of Significant Factors	3	2	2	3	3	2	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	3	2	2	3	2	2	
5. # of Outcome Attributes	3	3	3	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
6. Outcome Measurability	4	4	4	3	4	3	3	4	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
7. Contingent Decisions	1	3	3	1	2	2	3	2	3	1	2	3	2	2	2	2	2	2	2	2	3	2	2	2	2	2	2	
8. Probabilistic Dependence	4	3	3	4	5	3	3	3	3	3	4	3	3	3	4	3	3	3	5	3	5	5	4	4	5	4	4	
9. The Degree of Risk	3	3	3	3	1	1	2	3	3	4	1	2	3	1	1	1	3	1	1	1	1	1	1	1	1	1	1	
10. Review and Approval	2	1	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
11. Structural Uniqueness	2	2	1	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	2	3	3	2	2	2	
12. Quantity of Information	2	1	2	2	2	1	1	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	
13. Variability of Info. Value	2	3	3	2	2	2	2	2	3	2	3	3	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	
14. Reliability of Information	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
15. Time Available	5	3	3	4	4	3	4	3	3	5	3	2	4	2	2	4	3	2	3	2	2	4	2	2	2	3	3	
16. Frequency of Decision	4	5	5	4	4	3	4	4	5	4	3	2	3	2	2	3	2	2	3	2	2	3	2	2	3	3	3	

(Warfare Type)

Key:

O - Objectives
A - Assets
P&T - Positioning & Timing
P - Planning
E - Execution
Em - Emergency

TABLE 5: ASSESSMENTS FOR ASW (Task Force level of command only)

Table entries refer to assessment scale response in Table 3.

Category / Characteristics	ASW (Warfare Type)								
	TFC (Level of Command)								
	O (Decision Function)			A			P&T		
	P	E	Em	P	E	Em	P	E	Em
1. DM's Resources	5	5	5	5	5	5	5	5	5
2. Importance of Decision to DM	2	4	2	4	4	3	4	3	3
3. # of Decision Strategies	3	2	2	3	2	2	2	2	2
4. # of Significant Factors	2	3	2	3	2	2	2	2	2
5. # of Outcome Attributes	2	3	3	2	3	2	2	3	2
6. Outcome Measurability	1	3	4	3	1	3	1	3	3
7. Contingent Decisions	2	2	3	2	2	2	2	2	3
8. Probabilistic Dependence	4	4	3	4	3	3	3	4	3
9. The Degree of Risk	1	1	1	1	1	1	1	1	1
10. Review and Approval	1	1	1	1	1	1	1	1	1
11. Structural Uniqueness	2	3	3	3	3	3	2	2	2
12. Quantity of Information	1	1	1	1	1	1	1	1	1
13. Variability of Info. Value	2	3	3	2	3	3	2	3	3
14. Reliability of Information	3	2	2	3	2	2	3	2	2
15. Time Available	4	2	2	3	2	2	2	2	2
16. Frequency of Decision	4	2	3	3	2	3	2	2	3

(Warfare Type)

(Level of Command)

(Decision Function)

(Decision Context)

Key:

O - Objectives

A - Assets

P&T - Positioning & Timing

P - Planning

E - Execution

Em - Emergency

category representing a decision made in strike warfare, at the first level, relating to objectives, in a planning context. An example of a decision in this category is a fleet commander's order to a task force to attack an enemy airfield in support of an ally. The assessment scale response was "3," which from Table 3 indicates that four to six primary decision alternatives are available to the decision-maker in this situation. For instance, the fleet commander could support an ally with a naval blockade, an amphibious landing, shore bombardment, or simply a show of force.

Although the assessments are not definitive, it is interesting to examine the results briefly to check their credibility and observe general patterns in the assessments. Characteristic 1, the decision-maker's resources, corresponds directly to the level of command. The assessments for Characteristic 2, the importance of the decision to the decision-maker, indicate that decisions relating to objectives seem to be the most important at the fleet level. At lower levels of command they are less important than decisions relating to assets and to positioning and timing.

Turning to the "complexity" group of characteristics, it appears the number of decision strategies (Characteristic 3), is higher for higher levels of commands, although this is not always the case. Assessments for Characteristic 4, the number of significant factors, indicate that more factors are considered in a planning context than in execution or emergency situations. From the assessments for Characteristics 5 and 6, it is clear that the number of outcome variables required for an adequate problem description is directly correlated with the level of command: more variables are required at higher levels. In addition, a greater percentage of the outcome variables are subjective at higher levels of command.

Characteristic 7 gauges the importance of contingent decisions in the decision-making process. Not surprisingly, contingencies are most important in a planning context, and least important in an emergency situation. Probabilistic dependence, as measured by Characteristic 8, does not appear to exhibit any strong patterns. It seems

there is a higher level of probabilistic dependence at the unit level of command than at the other levels.

The degree of risk involved (Characteristic 9) is higher at higher levels of command, where high-consequence events such as political reaction are explicitly considered in the decision-making process. The assessments for Characteristic 10, review and approval, suggest that review is carried out more often for planning decisions, which take place over an extended time period, than for execution or emergency decisions. It also appears that decisions made at the fleet level are subject to more extensive review than decisions made at lower levels. The assessments for structural uniqueness (Characteristic 11) indicate that usually an old plan or procedure can be adapted to the current problem.

The results for the "information" group confirmed the notion that the information processing requirements are greater at higher levels of command. The quantity of information processed (Characteristic 12) is highest for the fleet commander. It is also higher for planning decisions than for execution or emergency decisions. The variability of information value (Characteristic 13) is also greater at the fleet level than at the task force or the unit level. The major observation for Characteristic 14, the reliability of information sources, is that reliability is lower for ASW than for strike warfare. ASW decisions are based on several information sources, each operating in a highly uncertain environment, and therefore the reliability of information from a given source generally will be low.

The final two characteristics are in the "timing" group. The responses for Characteristic 15, the time available for the decision, are directly related to whether the decision is made in a planning, execution, or emergency context. Characteristic 16, the frequency of the decisions, is also related to decision context, but depends more heavily on level of command. Decisions of one type tend to recur more frequently at lower levels of command.

Implications for Decision Aid Design: An Example

The remainder of this section compares two typical decisions using the assessed characteristics shown in Tables 4 and 5. The implications of these characteristics for the design of suitable decision aids are also explored.

The decisions considered are taken from Table 2. They are: "defend an ally by attacking enemy forces," which is the example of the fleet, air strike, objectives, planning category; and "assign an ASW helicopter to investigate submarine contact," which is an example of the task force, ASW, assets, execution category. For brevity, we shall refer to the decisions by the level of command involved, terming them the "fleet decision," and the "task force decision," respectively.

In order to compare the two decisions, we shall make use of the assessments performed for their categories. The assessments for the fleet decision appear in Table 4, and those for the task force decision are in Table 5.

The first group of characteristics deal with "stakes." The assessments for Characteristic 1, the decision-maker's resources, reflect the fact that more resources are available to the fleet than the task force. This alone would indicate that a decision aid with a higher unit cost could be justified for a fleet commander. The other characteristic in the stakes group, importance of the decision to the decision-maker, indicates that while this decision is among the most important made by the fleet commander, the task force commander regards the decision facing him as less important than average. Thus, the fleet commander, faced with an important decision, would be willing to spend more time and effort using a decision aid if it was available, while the task force commander would probably ignore a complicated or time consuming aid for a relatively unimportant decision.

The overall implications for aid design are clear in this case. The fleet commander is making an important decision involving a high level of resources, so an expensive and sophisticated aid is justified. The task force decision merits an aid with a lower unit cost, and one that is relatively fast and easy to use.

Turning to the "complexity" group of measures, several further conclusions can be drawn. Characteristics 3 through 8 collectively indicate the "size" of the decision problem. The fleet decision involves a larger number of decision alternatives (Characteristic 3), and, as indicated by Characteristic 7, contingent planning is very important. Given the exponential increase in aid processing requirements as the number of decision strategies increases, we would expect that an aid with extensive computing power would be required for the fleet decision. The same is true because of the larger number of factors (Characteristic 4), and outcome variables (Characteristic 5), involved in the fleet decision.

Characteristic 6 indicates that a higher percentage of the outcome variables are subjective in the fleet decision than in the task force decision. While both commanders will think in terms of outcomes, such as enemy forces destroyed and own forces lost, the fleet commander will also consider more global outcome attributes, such as world reaction, the political implications of military actions, etc. This means the aid must allow the fleet commander to define and assess outcomes in a form appropriate for the decision situation and the commander's interpretation of it. A flexible interactive aid would be appropriate. On the other hand, at the task force level, an aid that is preprogrammed to handle only certain objective outcome variables would be more suitable.

The latter point leads directly to Characteristic 11, structural uniqueness. The assessment indicates the fleet decision is somewhat unique, while the task force decision occurs on a regular basis. Again, this indicates the need to dynamically modify the aid in the case of the fleet decision. On the other hand, a pre-programmed aid, requiring only the input of new data, might be acceptable for the task force decision.

Characteristic 9 indicates risk is an important factor in the fleet decision, while it has little bearing on the task force decision. Thus, a decision aid for the fleet decision should be capable of dealing with risk aversion and monitoring the sequences of events that could lead to a very costly outcome. Both an alerting and a devil's advocate capability would be appropriate for the fleet decision. On the other hand, the task force commander may need only a status display for his ASW decision.

Characteristic 10 considers review and approval. The assessment indicates that while the fleet decision is regarded as a tentative decision that is subject to review, the task force decision is firm. This stems from the fact that the task force decision is an execution decision, with less time available for review by higher levels. Thus, an aid for the task force decision need not summarize or store the information and logic upon which the decision is based to the same extent as an aid for the fleet decision.

In the "information" group, Characteristic 12, the quantity of information, indicates the fleet commander (and his staff) processes a larger amount of information than does the task force commander. This is not surprising given the resources involved, and the fact that the fleet decision takes places in a planning rather than an execution context. The implication for aid design is that the fleet decision requires greater data processing and storage capability.

The assessment for Characteristic 13 states that the value of incoming information varies more for the fleet commander. The value of information messages is closer to being constant in the case of the task force commander. Again this stems largely from the fact that the fleet decision occurs at the planning stage, where a large amount of information is being screened, while the task force decision occurs in an execution context. The decision aid used for the fleet decision should be able to sort or weight data as to its importance.

Characteristic 14 indicates that the task force commander must deal with less reliable data sources than the fleet commander. This stems from the type of warfare involved in each case. ASW is characterized by more uncertainty than is strike warfare. An aid for the ASW decision can do little to improve data reliability, but it can give the task force commander an indication of the range of uncertainty, and possibly add redundancy to the information processing.

The differences between the two decisions as measured by the two characteristics in the "timing" group are fairly apparent from the decision context. The fleet decision, made in a planning context, is made over a period of several weeks, allowing a very thorough analysis to be performed. Since the decision is also made very infrequently, it is feasible to use a flexible decision aid that requires the user to define the decision logic. The task force decision on the other hand is made in a combat situation. The time available to use an aid and to reprogram it between decisions is limited. This aid should be pre-programmed and easy to use.

In summary, it is apparent that a more flexible and sophisticated decision aid is required for the fleet decision than for the task force decision. The fleet problem is "larger," in terms of decision alternatives, outcome variables, and significant factors, and are more complex. More uncertainty and risk are involved in the fleet decision, and the information structure of the fleet decision is more complex. The decision characteristics suggest that the fleet decision calls for an interactive aid which can be reprogrammed between applications, while the task force decision requires a static aid which is largely pre-programmed.

These characteristics are not sufficient by themselves to justify a highly sophisticated aid for the fleet decision. However, the characteristics in the "stakes" group indicate that the potential losses and gains to the Navy are much greater for the fleet decision than for the task force decision. Thus, in terms of the optimal allocation of scarce Navy resources, the use of a more expensive and sophisticated aid for the fleet decision would be justified.

V. THE CHARACTERISTICS OF DECISION AIDS

Although the project plan for this research does not call for the development of a taxonomy of the characteristics of decision aids, a preliminary version of such a taxonomy has been formulated. It is presented here to show approximately how the three taxonomies can be used together to evaluate the appropriateness of decision aids. The aid characteristics discussed here are intended as a first step in the development of a comprehensive taxonomy, and are subject to revision. Additional research will be needed to test, refine, and expand these characteristics.

There are many kinds of decision aids that could be used for Navy command and control, ranging from simple checklists to large electronic data bases and computer-generated displays. Certain characteristics are applicable to all of these aids, while others are relevant only to the more sophisticated aids. For example, while it is meaningful to measure the unit cost of any aid, a characteristic like an aid's communications capability is more relevant to electronic devices than it is to simple static aids.

The characteristics used to describe decision aids should be sufficiently general to allow a meaningful assessment of the properties of many different kinds of aids. If the characteristics are overly specific to a particular technology or methodology, they will provide little guidance for comparing different classes of aids. The characteristics should be capable of characterizing such diverse aids as: displays, data banks and information-retrieval systems, combat or engagement models, assessment procedures for subjective information (i.e., uncertainties and preferences), tools for formulating models, devices for data sorting and restructuring, algorithms for pattern recognition and warning, checklists, weapons control and coverage calculations, training simulators, and inference calculations.

Although the taxonomy must be sufficiently broad in scope to characterize a wide range of possible decision aids, the characteristics must also be operational in order to provide meaningful guidance to those developing and selecting aids. This means that each characteristic should be defined in terms that can be related to the measurable properties of an aid. Research will be needed to establish precise and understandable measures for some of the characteristics in the preliminary taxonomy without limiting their applicability to a few specific decision-aiding techniques or devices.

The Taxonomy of Decision-Aid Characteristics

The preliminary taxonomy of decision-aid characteristics is shown in Table 6. The taxonomy consists of fourteen characteristics.

There is a direct relationship between the taxonomy of decision characteristics, detailed in Section III, and the taxonomy of decision-aid characteristics. Each decision characteristic has implications for the features of a decision aid that would be appropriate for that decision. A preliminary mapping between the two taxonomies has been developed, which links each decision characteristic to a series of decision-aid characteristics. The mapping can also be reversed so that each aid characteristic is linked to one or more decision characteristics. Table 7 presents the linkages. For example, the decision characteristic measuring the time available for a decision has an impact on four of the aid characteristics: cost of use, reliability, data processing capability, and complexity of the user interface. Working in the other direction, the decision aid characteristic measuring the cost of use is related to three decision characteristics: importance of the decision to the decision-maker, structural uniqueness, and the time available for a decision.

Each of the decision-aid characteristics and its corresponding decision characteristics are discussed in the following paragraphs.

The first decision-aid characteristic is <u>the unit cost of the aid</u> (i.e., the cost of each aid that is deployed). The unit cost can include a proportional share of the resources expended to develop the aid. The reason for

Table 6: A PRELIMINARY TAXONOMY OF THE CHARACTERISTICS OF DECISION AIDS

1. Unit cost of the aid, including a proportional share of the development costs.

2. Cost of using the aid, including the level of effort required to use or program it.

3. Support requirements, including data sources, other aids and equipment, and physical space.

4. Reliability, including redundancy, self-monitoring, and a capability for graceful degradation.

5. Data processing capability, as measured by the number of calculations and amount of data that can be processed per unit time.

6. Data storage capability, including both rapid-access and slow-access storage.

7. Capability to maintain data security, including access control and encoding.

8. Data verification capability, including error checking and cross checking data from multiple sources.

9. Communications capability, including data transmission rates and number of communication channels.

10. Ability to prioritize its own operations, including the ability to interrupt and restart a procedure.

11. Facilities for testing and updating algorithms, as measured by the ease with which procedures or analyses can be restructured.

12. Ability to monitor and update information, including information sorting and screening.

13. Complexity of the aid-user interface, including the level of training required of the user, the sophistication of the algorithm, and the extent to which the aid summarizes and supplies its outputs.

14. Compatibility with existing systems and procedures.

TABLE 7

RELATIONSHIP BETWEEN DECISION CHARACTERISTICS AND
DECISION-AID CHARACTERISTICS

Decision Characteristics \ Aid Characteristics	1. Unit cost	2. Cost of use	3. Support requirements	4. Reliability	5. Data processing capability	6. Data storage capability	7. Data security	8. Data verification	9. Communications capability	10. Prioritized operations	11. Test and update algorithms	12. Monitor and update info.	13. User interface	14. Compatibility
1. DM's resources	√		√											
2. Importance of decision to DM		√		√			√							√
3. # of decision strategies					√	√								
4. # of significant factors					√	√								
5. # of outcome attributes													√	
6. Outcome measurability													√	
7. Contingent decisions					√	√				√		√		
8. Probabilistic dependence					√	√								
9. Degree of risk												√		
10. Review and approval			√			√							√	
11. Structural uniqueness		√									√		√	
12. Quantity of information									√			√		
13. Variability of info. value								√	√	√		√		
14. Reliability of info.								√	√	√		√		
15. Time available		√		√	√								√	
16. Frequency of decision					√									√

considering the unit cost of the aid rather than its total development and deployment costs is that we would like to compare the cost of a single aid with the resources of the decision-maker who uses it. It is unlikely that an aid would be deployed if its unit cost exceeds or even approaches the value of the decision-maker's resources. However, an expensive research and development effort would be justified if it produces a low-cost aid that could be used by a large number of decision-makers.

Although this characteristic deals indirectly with the cost of developing an aid, it may be useful to consider development costs, or perhaps development time, as a separate characteristic. While these additional decision aid characteristics might be useful for guiding research programs, they are difficult to relate to the characteristics of individual command and control decisions.

The second decision-aid characteristic is <u>the cost of using the aid</u>, which is measured by the level of effort required to operate it and interpret its results. If an aid requires the user to program it or supply it with information about a decision situation, this effort is part of the cost of using the aid. The level of effort that a decision-maker is willing to devote to using a decision aid is directly related to the importance of the decision to the decision-maker. Another decision characteristic related to the cost of using an aid is the structural uniqueness of the decision situation. A decision-maker is more likely to spend the time required to use an aid if he is facing a situation where existing plans and procedures provide insufficient guidance. A decision-maker must also weigh the effort required to use the aid against the time available for the decision. An aid will never be used if it requires more effort that can be supplied in the time available.

The third characteristic of decision aids is <u>the support requirements</u> for maintenace and operation of the aid. This includes the data that must be supplied from other commands or data bases, any equipment that must interact with the aid or transmit information for it, and any people or facilities needed to maintain and provide space for the aid. For an aid to be practical,

its support requirements cannot exceed the resources that can be provided by the decision-maker and the commands that support him. Thus, the decision-maker's resources indicate the maximum support requirements that would be appropriate for a decision aid. Another decision characteristic that affects an aid's support requirements is the extent of review and approval required to make a decision. If it is necessary to document and justify the logic used to reach a decision, the aid will need appropriate information about the decision logic from all of those who contribute to the decision process.

The fourth decision-aid characteristic is reliability. Reliability includes any redundancy that is built into the aid, its ability to monitor its own operations and detect errors and failures, and its ability to continue operating in a degraded mode rather than cease functioning if components fail or it is overloaded with information. If the decision being supported by the aid is important to the user, then its reliability should be high. A decision-maker will only use an aid to help him make important decisions if it is something he can depend upon. The reliability of an aid should also be high if the time available for decision-making is short, since there will be little time to recover if the system fails.

The fifth decision-aid characteristic is the aid's data processing capability, as measured by the number of calculations or the amount of data that can be processed in a specified amount of time. A variety of decision characteristics have implications for an aid's data processing capability, especially those characteristics that describe the decision's complexity. For instance, the number of decision strategies considered by the user affects the amount of information that must be processed by the aid. The amount of information that must be processed is compounded if the alternatives being considered are contingent on future events. In this case the aid may have to keep track of more than one alternative until some of the uncertainties surrounding the decision are resolved. The required data processing capability also increases with the number of factors that could have a significant impact on a decision outcome. Determining the implications of these factors will require additional processing if the factors are interdependent. If the time available for

the decision is short, the aid must be capable of processing the necessary information rapidly. Similarly, if a particular decision occurs frequently, the aid must have sufficient dedicated data processing capability to be available each time the decision arises.

The sixth decision-aid characteristic is the aid's data storage capability, including both rapid-access memory and slow-access data storage units such as tapes or disks. An aid's data processing and data storage capabilities are closely related, so many of the same decision characteristics affect both. The amount of storage required in a decision aid (especially a static aid) increases with the number of decision strategies considered and the number of factors that the decision-maker believes could have a significant impact on the outcome. Storage requirements also increase if the decision involves contingent courses of action or many dependencies among the outcomes and the factors that influence them. Another decision characteristic that can greatly increase data storage requirements is the extent of review and approval needed to make a decision. A large volume of information must be stored if all the logic and data that went into a decision must be presented to higher levels of command.

The seventh decision-aid characteristic, the aid's capability to maintain data security, is especially important for decisions concerned with gathering and disseminating intelligence. This includes the aid's facilities for limiting access to information and communicating it in a secure manner (i.e., encoding). The extent to which an aid should maintain data security depends on the source of the data and the importance of the decisions for which it is used.

The eighth decision-aid characteristc is the aid's data verification capability. This means that the aid should be capable of detecting errors in the data by cross-checking information from multiple sources and using internal processing and storage procedures that are self-checking. One decision characteristic that determines the usefulness of an aid's data verification capability is the variability of information value. If a decision is based on a few pieces of information that are significantly more valuable than the rest, then it is especially important that the aid be capable of checking the validity of that information. A data verification capability may also

be needed if the reliability of some of the sources providing information to the decision-maker is low. In this case, the aid should be capable of identifying and verifying information from unreliable sources.

The ninth decision-aid characteristic is the aid's communications capability, including the rate at which it can transmit data and the number of communications channels it can use simultaneously. This characteristic obviously does not apply to simple decision aids like checklists, but the fact that these simple aids do not have a communications capability is an indication of the range of decisions for which they are appropriate. The decision characteristics that have implications for an aid's communications capability are those that deal with the quantity and quality of information that must be processed. If an aid is to deal with a large volume of information, then it must have an extensive communication capability. If the variability of information value is high, the aid may need special communication capabilities to deal with very valuable (i.e., high priority) information. Also, if the reliability of the information sources is poor, the aid may need additional communications to check the information with redundant sources.

Under certain circumstances it is important that an aid have the ability to prioritize its own operations. This is the tenth decision-aid characteristic and it includes the ability of an aid to interupt a routine operation when important information is received, and then restart the operation at a later time. Prioritized operations are especially important if contingent decisions are being considered, since the aid may have to alert the user when the information needed for a decision has arrived. Similarly, the aid should be capable of prioritizing its own operations to deal with especially significant data when the variability of information value is high, or information that is received from an especially reliable source.

The eleventh decision-aid characteristic is the aid's ability to test and update algorithms contained in it. This characteristic is measured by the ease with which decision-aiding procedures or analyses can be restructured by the user. This facility is directly related to the extent to which the

structure of the decisions supported by the aid varies. If the same plans and procedures can be used for each decision, the aid can be preprogrammed to reflect their common structure and it does not need an ability to test or update algorithms. However, general-purpose aids designed to help a decision-maker deal with unique problems will need this facility.

The twelfth decision-aid characteristic is the aid's ability to monitor and update information, recognize important information patterns, and use the information to update estimates or summaries contained in its own data base. Included in this characteristic is an aid's ability to sort incoming information according to its importance, and screen out unimportant or irrelevant information. This capability is needed if the aid is to assist the user in making and implementing contingent decisions, since the aid will have to recognize the arrival of information upon which the decision depends. The ability to monitor and update information is especially important if the degree of risk associated with the decision is high. In this case, the decision-maker will need to keep track of any information that might indicate whether he should take steps to avoid a situation that could be very costly. If the quantity of information processed by the aid is very high, it is not feasible to store each piece of information as it is received and some type of information updating is needed. If the variability of information value is high, the aid needs an ability to place a greater weight on the more valuable information and update its internal data base accordingly. Similarly, the aid should be capable of recognizing and placing greater weight on information from reliable sources in situations where the reliability of information sources varies.

One of the most important decision-aid characteristics is the complexity of the aid-user interface. This complexity is measured by such things as the level of training required by the user, the ease with which the user can understand any algorithms contained in the aid, the format in which the aid presents data to the user (e.g., geographical displays, graphs of projected quantities over time, tables of numbers, etc.), and the extent to which the aid summarizes

its outputs. The complexity of the user interface is influenced by the number of outcome attributes needed to adequately represent the consequences of a decision. If many attributes are important, the aid must be capable of summarizing the many possible combinations of outcomes. The aid may also be called upon to elicit and store some of the decision-maker's trade-offs among the outcome attributes. The type of data that the aid can present to the decision-maker depends upon whether or not the outcomes are measurable. If the outcomes are defined only in qualitative or subjective terms, the aid will have to provide the decision-maker with a fairly complete description of the range of possible outcomes in order for him to assess or interpret the subjective attributes. The complexity of the user interface also depends on the degree of review and approval required to reach a decision. If a decision must be presented to higher levels of command, an aid has to summarize the decision logic and the outcomes associated with various alternatives in relatively simple terms that can be understood by officers in other commands who may not have experience in using the aid. The format of the user interface depends on whether the structure of the decisions it supports is fairly constant. If it is, the interface between the user and the aid can be prestructured to display data in a form specific to a particular class of problems. Finally, if the time available for making a decision is short, the user interface must be easily interpreted so a user can assess the aid's results rapidly.

The last decision-aid characteristic is the aid's compatibility with existing systems and procedures. While compatibility is obviously desirable, there are some decision characteristics that would make it more likely for a novel decision aid to be accepted and used for tactical decisions. If the decision being supported is very important to the decision-maker, he would be more likely to modify existing procedures to accomodate an effective aid. However, if the decision is made frequently, the use of an incompatible aid may not justify repeated departures from existing procedures.

Comparing Desirable Aid Characteristics with Features of Decision Aids

After the taxonomy of decision-aid characteristics has been tested and improved, it can be used with the other taxonomies to indicate the characteristics that an aid should have to help someone make a given decision. If a decision aid is proposed to support a particular decision, the aid's features can be compared to the set of desirable characteristics generated by the taxonomies to determine whether the aid is appropriate.

Appendix A outlines an evaluation of a hypothetical decision aid using the preliminary taxonomy of decision-aid characteristics. The analysis begins by considering the decision in terms of the taxonomy of decision characteristics. From there, desirable decision aid characteristics are inferred. Then the features of the hypothetical aid are compared to the characteristics it should have. Such an evaluation could be used to decide the best aid for a given situation, and to indicate ways in which existing aids could be improved.

VI. GENERAL CONCLUSIONS

Numerous specific comments and conclusions are presented and discussed in the preceding sections. This section contains some general conclusions about the usefulness of the taxonomies for designing and evaluating decision aids.

(1) It is possible to assess an operational set of characteristics for tactical command and control decisions, and to determine the properties that decision aids should have to support them. The appropriate characteristics for a decision aid can be inferred from the characteristics of the decisions it supports. The design of a decision aid can be guided or evaluated by identifying the decisions it supports, the characteristics of those decisions, and the corresponding characteristics that the aid should have.

(2) Many of the decision characteristics that directly influence the design of suitable decision aids are difficult to assess without structuring a decision in detail. This in turn, requires a fairly complete description of the decision situation, often in more detail than that specified by the decision categories.

(3) The categories of tactical command and control decisions are not specified in sufficient detail to cause every decision in a category to have the same characteristics. It may be possible to define more specific decision categories by either subdividing the existing decision categories or replacing them with an enumeration of specific decision tasks (e.g., "select a landing zone for an amphibious attack" or "select the most effective means of attacking a target"). However, definition of more specific decision categories probably means that there will be a very large number of them (in a related research project, investigators at Perceptronics, Inc., defined over 100 specific decision tasks for a single level of command in charge of amphibious landings). Thus, unless the range

of possible decisions can be restricted to something less comprehensive than Navy command and control, the number of decision categories may grow until it becomes impractical. There are two ways to solve this problem. One is to assess representative characteristics or ranges of characteristics for a few global categories. The other is to bypass the decision categories by describing in detail the decisions associated with each aid. In practice, the selection of one of these approaches will depend on the generality of the decision aid under consideration.

APPENDIX A

EVALUATION OF A HYPOTHETICAL DECISION AID

This appendix demonstrates the use of the taxonomies developed during this research. A pilot evaluation of the appropriateness of a hypothetical decision aid for a specific decision situation is performed. All of the data used (i.e., the characteristics of the decision and of the aid) have been fabricated, and are intended for demonstration purposes only.

Suppose we are concerned with a computerized aid that helps Navy personnel evaluate airborne threats to a task force, prioritize the threats, and coordinate the defensive actions of various units within the task force. These decisions fall into the following category (using the taxonomy of decision categories). They are <u>AAW</u> decisions at the <u>task force level</u> to <u>specify subobjectives or subtasks</u> for defensive units during the <u>execution</u> of task force operations. Part of the Navy Tactical Data Systems (NTDS) is designed to help Navy personnel make these decisions. The hypothetical aid described here is not based on a study of the NTDS, but is similar to NTDS. An exact description of NTDS is not needed to demonstrate the manner in which the taxonomies should be used.

The following paragraphs give a set of hypothetical characteristics for this decision, using the taxonomy of decision characteristics. They also outline the implications of each characteristic for the design of an appropriate aid, using the preliminary taxonomy of decision-aid characteristics. Characteristics from the two taxonomies are underlined. At the end of this appendix the set of desirable aid characteristics is compared to the features of the aid.

Decision Characteristic 1: The <u>decision-maker's resources</u> in this case consist of the men and equipment in the task force. Even though the decision is made by an officer in the CIC, he is a surrogate for the task force commander and has the defensive resources of the task force at his disposal. One implication of this characteristic is that the <u>unit cost of the aid</u> (i.e., the

cost of each installation that supports task-force decision-making) should not exceed a small fraction of the value of the task force. In other words, an effective aid costing a million dollars per installation might be acceptable, but one costing a billion dollars would not. Another implication of this characteristic is that support requirements for the aid (including information from other sources, interaction with other decision aids, and the aid's requirements for physical-space and power) must not exceed those that can be provided by a task force and its supporting forces. In this case, the aid should not require real-time data generated outside the task force, and should be small enough to fit in a small room.

Decision Characteristic 2: The importance of the decision to the decision-maker is relatively high (i.e., in the top 10 percent of the decisions he makes). This means that the cost of using the aid, including the level of effort required to operate it, can be high without deterring people from using it. It also means that the reliability of the aid must be good if the decision-maker is to depend on it. This characteristic also implies that the aid's data security could be important, although in this case security is provided by limiting access to the CIC. Finally, the importance of the decision means that existing procedures could be modified to accomodate an effective aid, even if it is not entirely compatible with existing systems.

Decision Characteristic 3: The number of decision strategies considered by the decision-maker is relatively limited. At most two or three threat classifications and a similar number of defensive actions are considered for each threat. This means that the amount of data processing and storage required for the aid to enumerate and compare the strategies is also limited. In this case, it is probably sufficient for the aid to identify those defensive weapons closest to the threat and for the user to select some of them.

Decision Characteristic 4: The number of significant factors that should be considered in reaching the decision is moderately high (i.e., approximately six to nine). They include a threat's speed, altitude, and

distance from the task force, and the position and capabilities of the defensive forces. Keeping track of all these factors in a form that can be used by the decision-maker requires a significant amount of data processing and storage. Even though the previous decision characteristic did not indicate the need for a lot of data processing, the requirements imposed by this decision characteristic will have to be met.

Decision Characteristic 5: The number of outcome attributes that must be considered to adequately represent the consequences of selecting various alternatives is small, probably three or less. The most important outcome attribute is the amount of damage caused by a threat, but the decision-maker may also have to consider the future position and capability of his defensive forces. This means that the aid can have a fairly simple interface with the user (i.e., display capability) that simply ranks alternatives on the basis of the first attribute, and summarizes the other attributes in case the user wants to incorporate them in the decision.

Decision Characteristic 6: All of the relevant outcomes are measurable. This characteristic means that user interface can consist of a few numbers to summarize the outcomes, rather than a more complete description that requires more interpretation on the part of the user.

Decision Characteristic 7: Contingent decisions are relevant to the evaluation of threats and coordination of defensive actions, but typically they are not as important as the immediate selection of a course of action. For example, an officer might decide to move the CAP into position to attack a suspected threat, but condition the attack on further information about the threat's identity. However, the limited time available to consider each threat means that most decisions will be unconditional. One implication of this characteristic is that relatively little data processing and storage will be needed to make sure that a contingent decision is implemented when the necessary information is received. However, the aid will have to monitor and update information as it is received, and then prioritize its own operations to alert the user when the information needed for a decision has arrived. These capabilities are needed even if only a few contingent decisions are made.

Decision Characteristic 8: The dependence of the outcome on the major factors in the decision is probabilistic. For instance, the fact that an enemy aircraft has succeeded in getting close to the task force does not necessarily mean it will be able to damage one of the ships. The amount of damage an enemy aircraft or missile will cause depends on such variables as the proficiency of those manning the defensive weapons, the point at which they interpret the threat, and the type of threat (e.g., an airplane or a missile). Thus, a moderate number of variables must be considered to estimate the damage that could be caused by an air threat (i.e., roughly two to five variables). This means that a signicant amount of data processing and storage is required to decide which threats are the most dangerous and which defensive systems have the best chance of minimizing the damage they could cause.

Decision Characteristic 9: The degree of risk associated with this decision is fairly high. An error in evaluating a threat or coordinating an effective defense could cause the loss of one or more of the major ships in the task force. Even if the chance that a threat could damage or sink a high-value unit is low, the aid should be capable of monitoring and updating information about the threat and warning the user if the threat is not stopped.

Decision Characteristic 10: Very little review and approval is required for tactical decisions to defend a task force against air threats. This means that the aid has no support requirements for units in the task force to provide data that would justify the decision to higher levels of command. It also means that large blocks of data storage are not needed to document the logic that went into the decision. Similarly, the user interface does not need to include a capability to summarize and present the decision logic.

Decision Characteristic 11: The structure of the decision is fairly constant. Usually, the same procedures are followed for each air-defense decision. This means that the effort required to use the aid can be kept to a minimum by preprogramming the aid's logic. It also means that the aid does not need

facilities for testing and updating algorithms. This decision characteristic also indicates that interface between the user and the aid can be prestructured to aggregate and display data in a form specific to the air-defense problem.

Decision Characteristic 12: The quantity of information that must be processed by the aid is very high since it includes all the radar and observation reports from each ship in the task force. The number of messages processed per day is probably in the thousands, although many of these are computer-to-computer communications. This means that the aid must have an extensive communications capability including several communications channels. It also means that the aid must be capable of monitoring and updating its own data as new information is received. The volume of data indicates the need for an aid that can help the user sort the incoming information and recognize significant patterns of events.

Decision Characteristic 13: Most of the information provided to those who evaluate air threats and coordinate defensive actions is important, and only infrequently does information arrive that is significantly more important than average. Since the variability of information value is not great, the aid should be capable of cross-checking and verifying data from several sources, rather than automatically relying on the most recent or reliable information. Another implication of this decision characteristic is that special communication capabilities are not needed for priority information, and the aid does not need to prioritize its own operations to handle incoming information. Similarly, the aid does not need a special capability to monitor and update information from a few very valuable sources.

Decision Characteristic 14: The reliability of the information sources providing data about air threats is fairly good, but not perfect. Often information about the nature of the threat is inconclusive or misleading, which makes it difficult to know exactly how to evaluate and respond to a threat. The proficiency of CIC personnel varies from ship to ship, and decision-makers often consider this in deciding how to use various pieces of information. This means that the aid should be capable of verifying data by

checking it against other information. It also means that the aid should have communications with a variety of redundant information sources to allow it to cross-check data. The aid should also be able to prioritize its operations to the extent that it reacts first to information from more reliable sources. Finally, the aid needs a data monitoring and updating capability that is capable of placing greater weight on information from reliable sources.

Decision Characteristic 15: The time available for making a decision is very short, often less than a minute. This means that the effort required to use the aid cannot be high. It also means that the reliability of the aid must be very high since there is little time to recover if the system fails. This decision characteristic also means that the aid must have the capability to process information in a short period of time. Finally, the interface between the aid and the user must be easy to interpret if the user is to assess the information rapidly.

Decision Characteristic 16: The frequency with which the decision occurs is quite high during combat. The need to evaluate air threats and coordinate a defense can reoccur in a matter of minutes. (While this seldom happens in non-combat situations, the aid is designed to deal with combat decisions.) This means that the aid must have sufficient dedicated data processing capability to be available on a continuous basis. In addition, the aid should be compatible with existing systems and procedures since it will be used frequently.

The discussion to this point has dealt with the characteristics the aid should have. The following paragraphs compare these desired aid characteristics to the aid's actual features in order to determine its appropriateness and identify any major deficiencies. Again, these "actual" features are hypothetical; they are presented here for illustration.

Aid Characteristic 1: The first characteristic of the decision aid is its unit cost. If we assume that each installation costs between 0.5 and 5 million dollars, then the cost is small compared to the value of the resources controlled by the decision-maker.

Aid Characteristic 2 : The cost of using the aid is fairly low for each threat evaluation and response (at most a few person-minutes), but a considerable amount of training and practice is necessary prior to the time the aid is needed. However, the importance of the decision warrants the required effort, which can be supplied within the time available for decision-making. Also, the unchanging structure of the problem means that there is little to be gained by increasing the generality of the aid and thus raising the effort required to use it.

Aid Characteristic 3 : The aid requires extensive support from radars and data processing facilities throughout the task force. However, these support requirements can be provided by the resources controlled by the decision-maker. There is no attempt or need to provide the aid with data that would reconstruct the decision logic for review and approval at higher levels of command.

Aid Characteristic 4 : The aid is fairly reliable, although the software is not designed to be self-checking or self-diagnosing. The importance of the decisions supported by the aid and the fact that there is little time to recover if it fails indicate that steps to improve the reliability of the system would be worthwhile.

Aid Characteristic 5 : The aid has a moderate data processing capability, but it does not appear to be keeping pace with improvements in computer technology. The current data processing capability is sufficient to deal with the limited number of alternatives considered by the decision-maker, but additional processing could be used to simplify the job of assessing the many factors that affect the decision. At present, the aid does not consider or support contingent decisions, nor estimate the outcomes associated with a course of action (i.e., damage and future defensive capability). Additional processing capability would allow the aid to help the decision-maker in these areas. Finally, the aid can respond quickly and as often as is necessary, although additional processing capability may be necessary to maintain this performance if the functions of the aid are increased.

Aid Characteristic 6 : The aid has sufficient storage to keep track of the alternatives available to the decision-maker and the factors that affect that decision. Additional storage would probably be required to allow the aid to implement a set of contingent decisions or keep an updated estimate of the outcomes associated with alternative courses of action. The aid does not have or need the large amount of storage needed to summarize the decision logic.

Aid Characteristic 7 : The aid does not provide data security, but it is not needed.

Aid Characteristic 8 : With the exception of correlating radar returns to determine an air threat's position, the aid does very little data verification. In particular, there are few checks to see that a threat is properly classified. This capability should be improved since there are several sources of potentially valuable information about each threat, but the sources are not equally reliable. One of the major deficiencies of the aid is that it does not attempt to screen nor de-emphasize relatively unreliable information.

Aid Characteristic 9 : The aid is capable of handling a high volume of communications over several channels. This is in keeping with the large quantity of information that must be processed. The aid does not have or need special channels for exceptionally valuable (i.e., priority) information. However, additional communications capability might be needed if the aid were programmed to collect enough redundant information to check the reliability of its sources.

Aid Characteristic 10 : The aid is capable of prioritizing and scheduling its own operations. This capability will be needed if the aid is extended to keep track of contingent decisions or respond immediately to more reliable information sources. However, the fact that most of the information it is currently processing is of equal importance means that an extensive self-scheduling capability is not needed.

Aid Characteristic 11: The aid does not have facilities for testing and updating algorithms, but these are not necessary for most of the decisions it supports because the structure of the decisions does not change. If new factors become important in the decision process, a better facility for updating algorithm may be needed.

Aid Characteristic 12: The aid is well-suited to monitoring and updating information. This capability is necessary because of the quantity of information being processed, the relevance of contingent decisions, the high risk involved, and the different reliabilities of information sources. Special monitoring of certain types of information is not necessary since most of the information received by the system is important.

Aid Characteristic 13: The user interface is fairly complex, although a proficient operator can access necessary information rapidly via graphics. This is important since the time for decision-making is short. A significant amount of training and constant practice are needed for competent use of the aid. Since the structure of the decision does not change significantly, it may be possible to simplify the user interface by preprogramming more of the decision-making process into the aid (e.g., automatic ranking of threats or estimation of possible outcomes). The aid's emphasis on displaying quantitative information is in keeping with the measurability of the data being processed. One reason the user interface has not been simplified is that there is seldom a need to document the decision logic for subsequent review and approval.

Aid Characteristic 14: The aid has been integrated with existing command and control systems. This compatibility is necessary since the decision occurs frequently, but the importance of the decision indicates that less traditional features could be incorporated into the aid even if it forced a change in other command and control procedures.

In summary, most of the aid's characteristics match those needed to support the decisions involved in evaluating air threats to a task force and coordinating a defense. However, there are several areas where improvements are needed. Giving the aid a self-diagnosis and "soft failure"

capability is warranted by the importance of the decision it supports. Better data verification facilities should be included in the aid so the operator does not have to figure out the relative weight to attach to various pieces of information. Better data verification may require additional communications and data processing capabilities. Finally, steps should be taken to simplify the user interface probably by programming the aid to handle more of the threat ranking and sorting steps currently done by the user. Since the aid already has an excellent graphics capability, it is doubtful that graphic improvements would significantly improve the user interface.

Although this example is hypothetical, it demonstrates each of the steps required to use the taxonomies. First, the decisions supported by the aid under consideration are identified. Next, the characteristics of these decisions are assessed, and the implications of these characteristics for the design of the decision aid are determined. Finally, the actual characteristics of the aid are compared with those that it should have to support the relevant decisions, and any significant deficiencies or areas for improvement are identified.

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